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DY AND DEVELOPMENT OF HIGHWAY ADVISORY RMATION RADIO

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December 1974
Final Report

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16. Abstract

A complete Highway Advisory Information Radio (HAIR) system was developed for audibly conveying traffic advisory and emergency information to the motoring public using a low power, limited coverage roadside transmitter at dedicated frequencies of 530 kHz and 1606 kHz. Types of information conveyed include emergency messages, warning tones indicating the approach of an emergency vehicle, advisory messages to alert motorists of anomalies ahead and alternate routes, and trip needs such as information pertaining to gas, food and lodging services. A major objective of the program was the development of special automotive receivers permitting the motorist to automatically receive the traffic messages while listening to his favorite AM or FM broadcast station. The radio transmission system utilized audio tone codes to achieve control of the automatic receivers; however, the system also permitted message reception with over 90 percent of existing AM automobile radios.

Surveys of commercial automotive AM receivers were made to determine tuning range limits and receiving sensitivities at 530 kHz and 1606 kHz. It was found that the capability of automotive AM radios to receive out-of-band signals depends almost entirely on field strength and not on the limits of tuning range.

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1.0 INTRODUCTION

The U.S. Department of Transportation awarded Contract DOT-FH-11-8045 to the Atlantic Research Corporation in May 1973, to assist the Federal Highway Administration (FHWA), Office of Research in developing a new concept in audio traffic control. The objective of this program is to devise a workable audible system for conveying traffic advisory and emergency information to the motoring public. This report covers Atlantic Research Corporation's effort over a 15-month period for research, development, test and evaluation of a Highway Advisory Information Radio (HAIR).

For some years now, broadcasting stations have been used to provide information in the form of spoken announcements on traffic and weather conditions. Various attempts have also been made to inform motorists of traffic conditions and other information using localized low power transmitters. All of the methods tried in this country require the motorist to tune his automobile receiver to a specific station either in the broadcast band or at its extreme end. The Europeans are currently evaluating three proposals, Radio Nederlands in the VHF band, B.B.C. in the MF band and a German proposal in the MF and VHF band. Common to all the European proposals is the acknowledgment that a better service of announcements to the motorists is required, preferably without seriously affronting the entertainment value of existing broadcast programs. It is with this objective in mind that the system described herein was developed.

The HAIR system has as a basic objective to provide traffic information to the motorist as it concerns his route and direction of travel while he is listening to his choice of AM or FM broadcast. His automobile radio will not be detuned, is completely automatic and following the brief advisory message will continue to receive the previously tuned AM or FM broadcast.

This objective is accomplished by the addition of an automatic receiver. Three models were developed: an adaptor model that can be added where an automobile receiver is already installed, a portable model where no radio is installed and an integrated model which encompasses the capabilities of the existing automobile radio and the adaptor model in a single unit.

When a motorist enters a highway he will pass through a short radio zone which provides a signal to switch his automatic radio to the correct channel pertaining to his direction of travel. This operation is performed without interruption to his normal broadcast reception. Subsequently, upon entering a radio zone where a message corresponding to the priority category he has selected (emergency, traffic advisory or trip information) is being transmitted his normal broadcast will briefly be muted and the traffic information announced. Immediately after receiving the message, his normal broadcast will return. Should an emergency vehicle approach, his radio will automatically announce this fact via an occulating tone.

The above functions are accomplished using FSK coding prior to and following a message. These codes turn on the automatic receiver, mute the automobile receiver and switch the automatic receiver to the proper channel. The receiver automatically decodes the received signal, matches the priority set in by the motorist and performs the required functions when the appropriate code is received and matched.

It was further acknowledged by the FHWA that nationwide implementation of such a system will take time. Consequently, it was required that the system be fully compatible with existing receivers by manual tuning.

The project involved five tasks: an Automobile Radio Survey, Development of System Requirements and Specifications, Design and Fabrication of a Prototype System, System Evaluation, and Development of Technical Information for Experimental License and Future Applications. During the course of the program, four design review meetings were also held to discuss key analysis, design and measurement milestones.

Over 350 automobile radios were measured to determine out-of-band tuning capability to form a basis for frequency selection for this system. From the results of this survey and frequencies offered by the FCC, it was decided to use 530 kHz and 1606 kHz as the directional channels for the system. Under a subsequent modification to the contract an additional 50 automobile radios were tested in greater detail to obtain receiving capability versus field strength. This test showed that 90 percent of the sample could receive 530 kHz in a field of 0.3 mV/m and 1606 kHz in a field strength of 0.8 mV/m. Detailed results of these tests are covered in Section 5.0.

Considerable analysis and system trade-offs of requirements were conducted and reported during the early phases of the contract. The resulting performance specifications were evaluated in operational scenarios and the most cost effective techniques were selected. These were discussed and agreed to during design review meetings with the FHWA technical representatives and form the basis for the system specifications. Details of this effort are reported in Section 2.

The design and fabrication effort was the most extensive and costly task. Delays were incurred due to vendor supply problems and in some cases, where lead times were intolerable, design changes were made. In one case, the design changes resulting from the unavailability of proper crystals caused severe degradation of performance and required additional redesign. However, crystals were finally obtained and the sensitivity problem resolved. This task is described in considerable detail in Section 3.0.

Laboratory tests of the completed receivers were conducted to determine compliance with the approved specifications. Extensive field testing was also conducted to determine antenna patterns and field strength characteristics, and system performance compliance. A modification to the contract during the task allowed testing of additional antenna systems including two types of "leaky coax" cable antenna. Results of the test and evaluation task is reported in Section 4.0.

FCC applications were filed and an experimental license received (Appendix F) under part 5 for operation of transmitters up to 15 watts at 530 kHz and 1606 kHz. A discussion regarding future use of these frequencies for traffic advisory information is covered in Section 6.0.

In summary, it is believed that the program was successful, and developed the HAIR concept into a feasible and viable system. Some of the system's possible applications include:

- Audio signaling to compliment (or replace) fixed and variable highway signs
- Single point diversion
- Route diversion
- Grade crossing warnings
- Overtaking emergency vehicles
- Trip planning
- Services availability.

There is an acknowledged need for this system on the nation's highways and it is strongly recommended that steps be taken to develop Federal policy for its implementation as rapidly as possible.

2.0 SYSTEM REQUIREMENTS AND SPECIFICATIONS

2.1 Initial System Requirements

The initial system requirements for the Highway Advisory Information Radio (HAIR) were provided by the FHWA in the Request for Proposal (RFP-54) package. The system concept described in the RFP consisted of:

a. A roadside transmitter, encoder and endless loop tape player

b. Three models of an automatic signing (HAIR) receiver.

The roadside transmitter would be required to transmit on up to three distinct frequencies and in addition provide for control of output power to permit its use as a low power channel identifier or as a medium power highway transmitter. The transmitter would be modulated by tone codes and voice messages recorded on an endless loop tape recorder. An encoder would be used to provide the necessary tone codes preceeding each priority message recorded.

The roadside transmitter, tape player and encoder would be housed in an enclosure to withstand the roadside highway environment and protected against vandalism, theft and tampering. Although no antenna requirements were delineated in the RFP, some discussions of antenna were brought up at the prebidders conference. This discussion resulted in a decision to leave the antenna design up to the bidder. It was noted, however, that coverage of approximately 4,000 feet of roadway would be required.

Three different types of automatic HAIR receivers would be provided. Receiver Model 1 would be an adapter type that will modify, without requiring internal changes or connections, an existing automobile receiver within the vehicle to provide the automatic pre-empt feature. The intention here is to provide a completely automatic HAIR receiver containing all the necessary circuits from RF through AF, digital decoder, speaker, and pushbutton channel/message selector. In addition, the automatic HAIR receiver would provide a signal that will deactivate the automobile receiver for the duration of a properly decoded message. Consideration would be given not to degrade the performance of the automobile receiver, and to provide a fail safe mode for the "in line" circuits such that the automobile receiver will continue to operate.

Receiver Model 2 would be a completely independent (portable) automatic HAIR receiver that can be used where no automobile receiver exists. This automatic receiver must provide its own built-in antenna or an easily attached external antenna. The unit would be compact, with all controls and speaker mounted on the front panel for easy control access and good sound fidelity. Clips or brackets would be used for easy attachment

to the dash. Models 1 and 2 could be exactly alike if the automobile radio deactivating signal and antenna tap circuits were integrated into this receiver. Models 1 and 2 would be designed to operate over the full range of vehicle environments normally encountered by standard equipment automotive radios.

Receiver Model 3 would have the automatic feature integrated within a standard automotive receiver. This unit would include all of the normal functions of a standard automotive receiver with full benefit derived from using common circuits in the receiver. Human factors guidelines should be considered in the design of the panel and controls to produce an effective package.

The RFP also described specific requirements the system must meet, namely:

a. Provide a priority access mode always available to receive emergency messages or tones from an emergency vehicle or highway patrol, and pre-empt any emergency warnings being broadcast from roadside transmitters.

b. Provide for discrimination of messages being broadcast for north bound traffic from being received by south bound traffic.

c. Provide for coding the automatic HAIR receivers for direction of travel at the entrance to a divided highway, with consideration given to manual override:

d. Provide for priority encoding of messages such that higher priority messages shall override a lower priority manually selected message.

e. Provide for the automatic HAIR receiver remaining silent until the vehicle moves within a radio zone and a coded message matching a manual selection is received.

f. Consider providing a built-in emergency warning tone and/or flashing light that is activated by a digital code or reproduce the received tone being broadcast from an emergency vehicle.

g. Provide for the transmission and reception of telephone voice bandwidths.

h. Consider frequencies above, below or notched out-of-voice bandwidth for communicating digital codes.

i. Provide for three categories of messages: emergency, advisory and trip needs in that hierarchial order for priority selection.

j. Provide a coding technique that allows easy synchronization, parity check, flexibility and low cost fabrication.

k. Consider human factors, low cost and good reliability for the vehicle environment in the system design for channel selection, indicators and illumination.

l. Provide a radio zone of coverage of approximately 4,000 feet.

m. Provide flexibility in the system design to allow integration of future applications.

The above describes the concept and initial system requirements provided by the FHWA for this Highway Advisory Information Radio system.

2.2 Final System Requirements

The initial HAIR system requirements were subjected to intensive analysis and review during the early phase of the contract. A baseline HAIR system was formulated and rigorously traded off against the conceptual requirements until a manageable set of system requirements and techniques could be defined. This analysis resulted in the following system requirements which were presented to and agreed by the FHWA design review committee.

Two frequency channels were decided upon to minimize the complexity of the system while meeting the requirement for discrimination of messages pertaining to traffic direction. The final selection of frequencies 530 kHz and 1606 kHz were based on the results of Task 1 survey and the options offered by the FCC, i.e., 530 kHz, 1606 kHz and 1612 kHz. The survey data from Task 1 indicated that a significant reduction on existing automobile receivers would result if 1612 kHz were selected rather than 1606 kHz. Consequently 530 kHz and 1606 kHz were selected, one for each direction of travel on a divided highway. Details of the Task 1 survey are covered in Section 5.0 of this report.

The baseline characteristics selected for the HAIR receiving system are capable of being automatically and/or manually preset to receive the transmitted messages intended for a specific direction of travel on the highway, capable of selection and reception

of priority rated transmitted messages, capable of reliable message reception with quickly and widely varying power densities, and no interference with standard broadcast reception when no messages are transmitted. The characteristics include a two-channel fixed tuned receiver capable of being automatically preset by a transmitted code to a specific channel. The receiver is to have manual override capability and be capable of muting the automobile radio when his car is within the reception range of transmitted highway emergency, advisory and trip information messages the motorist manually selected to receive. The HAIR receiving system that will fulfill the requirements have as a minimum the following features and characterisitcs:

- A switching device which will mute the automobile radio when the code at the beginning of the selected message is received.

- The same switching device should unmute the automobile radio when the end of the selected message is received.

- A two-channel fixed-tuned receiver, possibly of a tuned RF (TRF) or superheterodyne design so as not to interfere with the automobile radio reception, with automatic channel selection capability and manual override.

- The HAIR receiver should have capability of being automatically switched to either channel by a roadside transmitter at the highway access ramp dependent on the direction of travel.

- Once on the proper receiving channel for the direction of travel, the HAIR receiver should provide the motorist with selected highway transmitted messages based on priority. The message priority selecetions are emergency; emergency and advisory; and emergency, advisory, and trip information. During reception of the highway transmitted messages the standard broadcast reception on the car radio should be muted.

- The selectivity on each of the two channels of the fixed-tuned receiver should be adequate to prevent crosstalk from adjacent channels and/or frequencies.

- The tuned frequency on each of the two channels should be stable so as to allow reliable highway message reception under all adverse environmental conditions.

- The bandwidths of each of the two channels should be adequate to receive a standard telephone audio signal – 300 to 3000 Hz (RF bandwidth required for double sideband AM reception is 6 kHz).

- The gain of the fixed-tuned receiver on each channel should be adequate to allow the reception of signals comparable to ambient noise prevalent in the highway environment.

- The noise figure of the fixed-tuned receiver should be comparable to that of standard car radio.

- The fixed-tuned receiver should be capable of operating over wide input signal levels. This is very important in the situation at hand as the receiving antenna will be in the near field region of the transmitting antenna quite often. An AGC range of at least 60 to 70 dB is desirable.

- The channel the receiver is tuned to, as well as the message type selected by the motorist, should be clearly displayed to and easily interpreted by the motorist.

- The receiver should be ruggedly constructed and of reasonable cost.

- Visual indication of receiver audio capture and emergency vehicle warning.

- Audio volume and on-off control.

Specific requirements regarding message programming and coding are:

- Messages can be mixed serially.

- Messages of the same priority must be within a set of start and end-of-message codes.

- A separate code should be used for roadside emergency.

- An alternating code (0 1 0 1 . . . .) will be used for emergency vehicle warning.

- Voice communications from any emergency vehicle will use the same code and operating rules as roadside emergency transmission.

The enumerated fixed-tuned receiver characteristics are applicable to both the adaptor device for presently used car radios (Receiver Model 1) and the integrated radio (Receiver Model 3). The principal feature not applicable to the portable automatic receiver (Receiver Model 2) is: muting (switching "off" and "on" of an existing automobile radio). The Model 2 receiver, however, would require either a built-in or an external antenna.

The characteristics required in the transmitting system in addition to frequency stability, power level, modulation, and distortion control are capability of local or remote message insertion for transmission, of local or remote pre-empting of low priority messages when messages of higher priority have to be transmitted and automatic channel switching of the receiver system for the direction of travel. Ruggedness of construction of outside environment, modular construction, capability of carrier synchronization, usability with vehicular power supply and capability of adjustment of power levels are also required.

2.3 System Specifications

2.3.1 Introduction

After the functional aspects of the HAIR system were defined and the final system requirements fully delineated, detailed technical specifications for each component of the system were developed. These specifications provide a set of standards for the developed hardware to help ensure that the operational objectives of the overall HAIR system would be satisfactorily met. The complete list of approved system specifications, submitted to the FHWA during the contract prior to the hardware design task, contains further definition of system and component requirements, but, more important, includes the numerical standards which were required to be met with each system component. These technical standards specify practical, state-of-the-art performance levels based on existing, well-proven techniques.

This section presents a summary of the numerical specifications for each system component and includes statements of specifications not already implied in the Final System Requirements, Section 2.2. The results of laboratory and field testing of some of the system components are given in the Test Plan reports of Appendices A, B and C.

2.3.2 Encoder Specification

a. The encoder will use two tones which are on/off time modulated. The standard touch tone frequencies 852 Hz and 1477 Hz are recommended. A third signal which is an additional combination of both tones shall also be generated for use as a special function.

b. The tones shall be generated with an accuracy of ±1 percent under all ambient conditions.

c. A single tone (logical 0 or 1) will last a minimum of 0.1 second. A minimum silence period of at least 0.1 second shall follow before a second tone shall be sent.

d. The encoder tone output shall be adjustable from +3 to -20 dBm as measured in a 600-ohm audio system.

e. The encoder will be designed to operate over the temperature range of -30 to 60°C.

f. The speech processor shall provide volume compression, clipping and pre-emphasis in amounts determined to be suitable by detailed design results. Modulation peak clipping of 6 to 12 dB is acceptable.

g. The speech processor shall operate in temperatures of from 0 to 50°C.

2.3.3 Tape Recorder/Playback Specification

a. The tape recorder/player shall be capable of operating with standard NAB cartridges (endless loop) of various lengths.

b. The tape recorder/player shall exhibit the following technical characteristics.

Equalization	NAB Standard
Frequency Response	±2 dB, 50 to 3000 Hz
Distortion	2 percent or less at 0 VU recording level
Signal-to-Noise Ratio	50 dB or better
Wow and Flutter	0.2 percent or less at 3.75 in/sec (laboratory ambient)

Output	110 dBμ at 600 ohms
Input	both line and microphone
Power	105 to 125 volts ac 60 Hz
Operating temperature	0 to 50°C
Tape speed	NAB nominal ±1 percent.

2.3.4 Transmitter and Antenna Specification

The message zone is, for the present system, considered to be an unobstructed 0.75-mile segment of an interstate highway in one direction This comprises a maximum zone of approximately 75 feet wide by 4,000 feet long.

A basic requirement is to provide a vertical field of approximately 3 mV/meter minimum within the message zone without excessive signal outside the designated zone.

a. The transmitter shall provide an adjustable RF power output level of from zero to approximately 15 watts for each antenna location.

b. The transmitter shall comply with the following technical requirements:

Frequency	tunable to either 530 kHz or 1606 kHz
Frequency stability	±0.005 percent
Temperature range	0 to 50°C
Output impedance	50 ohms
Type of emission	amplitude modulated
Modulation capability	100 percent with an input level of -5 dBm from the speech processor at 400 Hz

c. The speech processor shall accept the output of the tape player and shall feed the modulator with the correct level to maintain peak modulations of 80 to 90 percent.

d. The matching networks shall be designed to accept up to 20 watts of input power at 50 ohms and provide phase adjustment and tuning to produce proper RF fields in the message zone or ramp switching zone.

e. The matching networks shall be operational without readjustment in temperatures of 0 to 50°C.

f. All (equipment) enclosures shall be sealed to prevent dust, moisture and other contaminants from entering.

g. The central enclosure shall be designed to maintain a temperature of no less than 0°C. Heaters may be utilized but the higher temperature shall be limited by shading, reflective surfaces and other means not requiring refrigeration. The design goal shall be more than 17°C rise on a hot summer day.

h. Interconnecting RF cables shall be commonly available 50-ohm coaxial cable such as RG/58.

2.3.5 Receiver Specifications

Except where noted these specifications apply to the adaptor, portable, and integrated HAIR receivers. The specifications are not absolute, for options are included in the design requirements. These options will allow for competitive designs and will also include operational aspects to allow a greater range of test programs.

a. The receiver will be a TRF type operating on two fixed-tuned channels, 530 kHz and 1606 kHz.

b. The TRF receiver may be of two types. The first type is conventional and uses a combination of LC and crystal filters to achieve selectivity. The second type is somewhat unconventional and uses LC tuned amplifier stages and synchronous product detection. It should be noted that although the TRF concept appeared superior during the specification phase of the project, additional analysis early in the design phase indicated a high development risk. Consequently, it was decided at that time and agreed to by the FHWA, to discard the TRF concept in favor of a dual-channel fixed tuned superheterodyne receiver.

c. Antenna Circuit

Adapter	The antenna circuit will provide a means for disabling the car radio antenna when a HAIR program is received.

Portable	The antenna shall be self-contained or, optionally, may be an external antenna with clips for attachment to the vehicle window or gutter.
Integrated	The standard broadcast receiver and the HAIR receiver channels shall employ a common antenna.

d. The antenna circuit shall be capable of surviving a discharge from a 500 pF capacitor charged to 5,000 volts.

e. The receiver shall be capable of developing a minimum of 2 watts at the speaker for either receiver channel with 1000 Hz modulation and an input signal of 20 microvolts at laboratory ambient condition or 40 microvolts at temperatures -30 and 60°C.

f. The minimum signal-plus-noise-to-noise ratio, 1000 Hz at 80 percent modulation, shall be as shown in dB below:

	RF Input Signal Level			
	20 μV	50 μV	1000 μV	100 kμV
SNR at laboratory ambient	16	26	34	34
SNR at -30 or 60°C	12	18	26	26

g. Adjacent channel gain shall be 23 dB less than the tuned channel gain.

h. Far channel receiver gain shall be 46 dB less than the tuned channel gain.

i. The bandwidth at frequencies with receiver gain of 3 dB less than the tuned frequency gain shall be 5.5 kHz to 10.5 kHz. The bandpass shall be equal above and below the tuned HAIR channel frequency within ±25 percent of the total bandpass.

j. The intermodulation product audio power shall be 20 dB less than the tuned frequency signal audio power.

k. The AGC sensitivity shall be 40 microvolts maximum.

l. Distortion with 100 mV (30 percent at 1000 kHz) input and approximately 2 watts audio output shall not as a design goal exceed 15 percent.

m. Audio output circuit

Adaptor and Portable	The HAIR receiver shall employ its own speaker. No component failure shall occur when the receiver is operated 30 minutes with the speaker open or short circuited.
Integrated	The audio circuits for standard broadcast and for reception of the HAIR message shall be common to the maximum possible extent.

n. As a design goal, the audio distortion with 5 mV input from 300 to 3000 Hz with 1.5 watts output shall not exceed:

(1) 5 percent at laborabory ambient or

(2) 10 percent over the temperature limits of -30 to 60°C.

o. The HAIR receiver will contain a tone decoder capable of receiving tone commands and acting thereon. The tone filters shall be capable of responding to the encoder tones $F_1 \pm 4$ percent and $F_2 \pm 4$ percent. Tone detection shall be converted to logic levels.

p. The receiver shall operate from the automobile battery. Normal operation shall be obtained with supply voltages of 11 volts to 16 volts.

q. With 5 mV, 30 percent modulation, 400 Hz, the output shall not change more than 3 dB over the voltage range of 14.4 to 12 volts. Standard output will be 1 watt. Rapid change in voltage – 10 volt/second – shall not cause intermittent operation.

r. Microphonic oscillation or transients (of noticeable amplitude) shall not be caused by operation of the receiver in the normal automobile environment.

s. Electrical transients on the automobile electrical system, when equipped with standard ignition suppression equipment, shall not cause objectionable audible output.

t. The HAIR receivers will be designed to operate over the temperature range of -30 to 60°C.

u. The HAIR radio will have an overall controlled response from 200 Hz to a minimum of 2500 Hz. Using a 1 kHz as a reference the response shall be as follows:

250 Hz	1000 Hz	3000 Hz
-3 dB	0 dB	-9 dB

3.0 SYSTEM DESIGN AND FABRICATION

3.1 Introduction

The principal effort in this contract has been the design, fabrication and testing of the electronic components of the HAIR system. This section presents a technical discussion and theory of operation of each component. The overall system is described first in block diagram form. This is followed by a description of the tone coding used throughout the system for automatic control of the HAIR receivers.

The results of a series of environmental and laboratory tests performed on some of the components are presented in Appendices A and B, and some field tests in Appendix C.

3.2 HAIR System Components

A block diagram of the HAIR transmitting system is shown in Figure 1, and of the three models of HAIR receivers in Figure 2. The entire system has been designed to operate on either of the following two channels:

Channel 1	530 kHz
Channel 2	1606 kHz

Digitally coded audio tones are employed with each transmitted message to provide automatic operation of the HAIR receivers. Details of the tone-coding control are presented in Section 3.3. All coded control signals for the system are generated by the encoder. Also, all voice messages originate at the encoder which contains a speech compressor.

The output of the encoder connects to a broadcast tape recorder/playback machine which utilizes cartridges containing short endless loops of tape for repetitive playback. It is intended that a routine message will be recorded on a tape loop for continuous playback. Emergency messages, however, may be sent from the encoder through the tape recorder to the transmitter in order to be transmitted in real time.

The subaudible tone, described in Section 3.3, may be either included in the composite voice-tone signal to the tape recorder or sent separately to the transmitter as indicated in Figure 1.

The transmitter is fixed tuned and provides up to at least 10 watts of average power output into a 50-ohm load. Two types of antenna systems may be used as indicated in Figure 1. One system utilizes one or more vertical whips with one wavelength spacing.

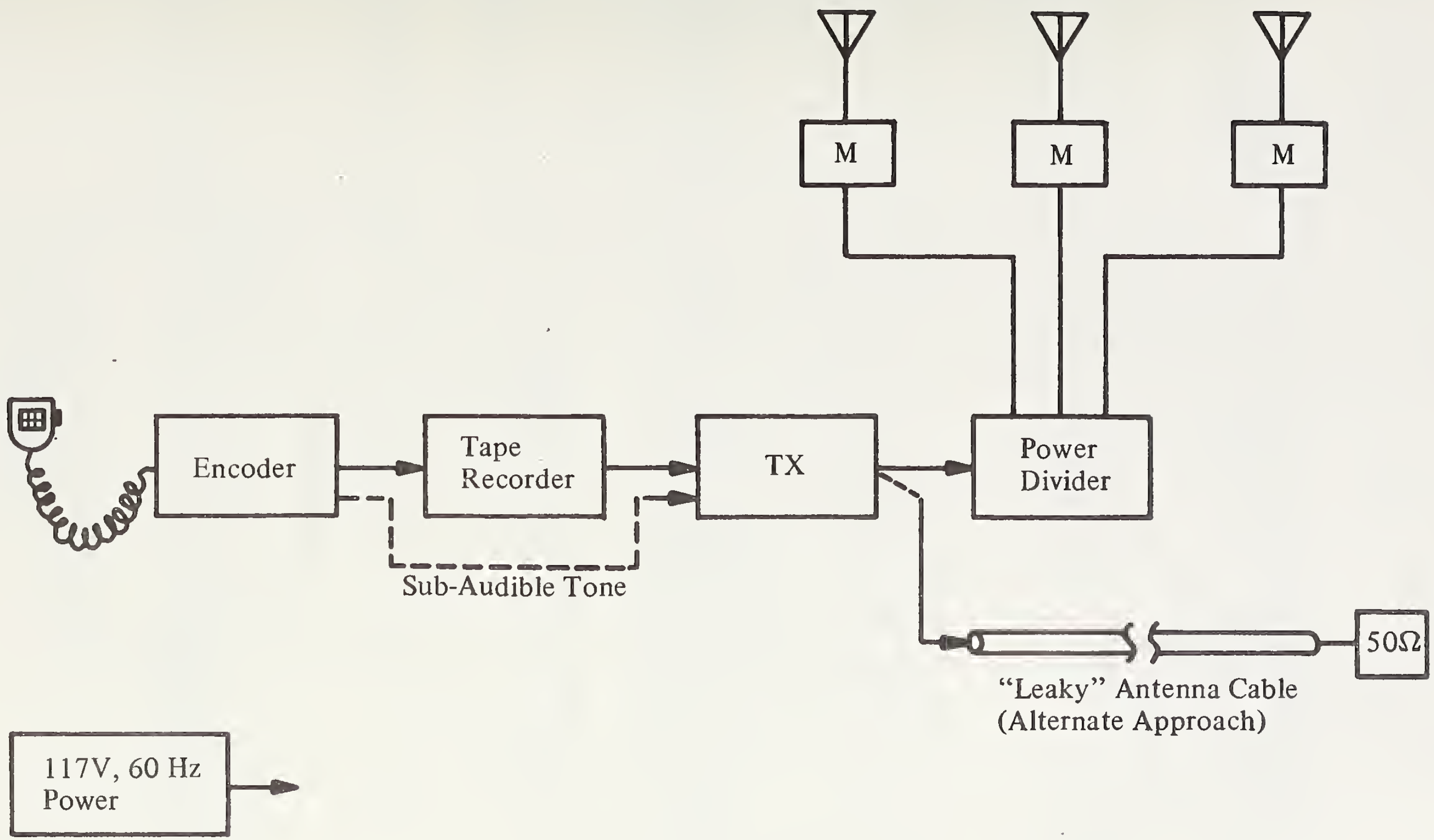


Figure 1. HAIR Transmitting System.

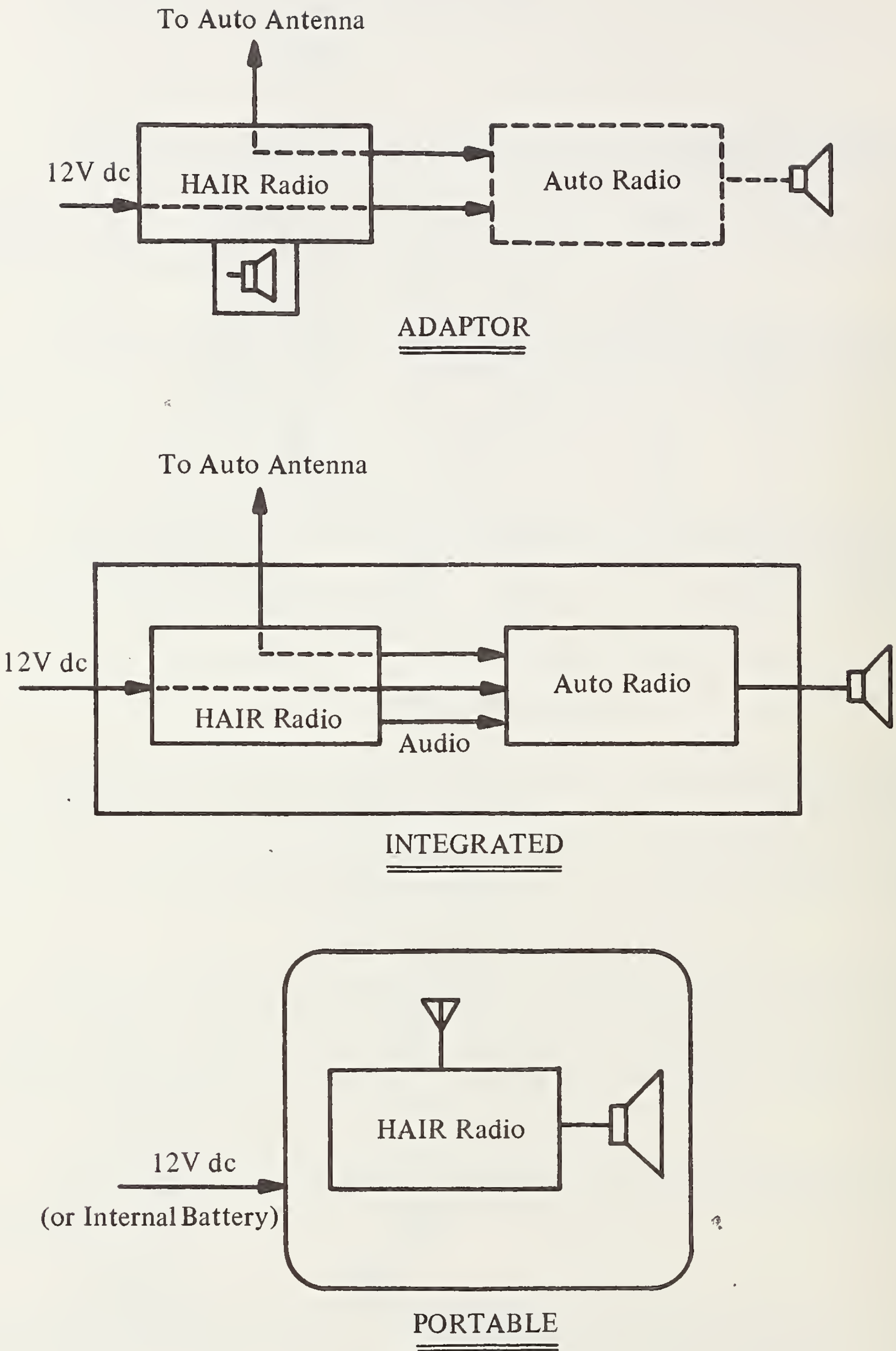


Figure 2. HAIR Radio Receivers.

The three antenna arrangements shown require the use of a three-way power divider and matching networks on the antennas. An alternate approach is the use of a long "leaky" cable antenna which may be buried alongside the highway. Such a cable will generally require termination in its characteristic impedance.

Three models of HAIR radio receivers have been developed as illustrated in Figure 2. Essentially identical circuitry for receiving the HAIR signals is used in each model. The primary difference among the models is the manner in which the HAIR receiver interconnects with the commercial AM receiver in the automobile.

The adaptor model consists solely of the HAIR receiver with an internal speaker. The automobile antenna connects directly to the adaptor radio, and a coaxial jumper cable connects the antenna signal from the adaptor to the auto radio. The adaptor radio receives 12-volt power directly from the automobile, whereas the auto radio receives the (switched) power from the adaptor radio.

The integrated model consists of the HAIR radio and the auto radio combined into one radio chassis. The antenna and dc power interconnections between the two radios are the same as described for the adaptor receiver. However, the HAIR radio in the integrated unit does not contain a speaker. The audio signal from the HAIR radio connects to the audio circuitry of the auto radio.

The portable model is a complete HAIR receiver that includes ferrite loopstick antennas and a speaker within the portable case. DC power for the portable radio may be obtained from an internal 12-volt battery or from an external wire connection to an automobile cigarette lighter.

The HAIR radio receiver is dual channel, fixed tune, and only one channel operates at a time. The channels may be switched either manually or automatically upon reception of an appropriate tone-coded message.

Each receiver contains a simple voltage regulator that stabilizes and filters the incoming supply voltage up to 16 volts dc.

3.3 Description of Audio Tone Coding

This section presents a detailed description of the audio tones utilized in the HAIR system to provide automatic operation and control of the HAIR receivers. The purpose of the tones is to cause the HAIR receivers to fulfill three basic requirements of the HAIR system as already specified in Section 2.0, System Requirements and Specifications.

a. The HAIR receiver must operate only while the motorist is located in the radio field of a HAIR transmitting station.

b. The HAIR receiver must become audible only for messages having priority equal to or greater than the priority level set by the motorist on his HAIR receiver.

c. The HAIR receiver must be capable of automatically changing the frequency channel upon reception of an appropriately coded signal.

In order to accomplish these functions the use of several audio tones incorporated with the voice messages of the HAIR radio signals was chosen as a practical method for achieving reliable, automatic control. Three tone frequencies are employed as described below.

82.5 Hz – This is a subaudible tone (SAT) which is continuous with all HAIR transmissions. Reception of this tone by a HAIR receiver enables the decoding circuitry and thereby permits the receiver to process the digital tone codes. Loss of SAT reception disables the decoder in the HAIR receiver thus turning off any audible HAIR message and unmuting the auto radio.

As a matter of interest, consideration was given initially to using AGC action upon reception of the carrier of a HAIR signal to accomplish this function. However, a serious drawback of this approach is that an interfering broadcast station could easily prevent release of the HAIR receiver after the motorist had left the radio field of a HAIR transmitting station.

852 Hz – This is an audible tone used to represent a logical 0 in the binary code word.

1477 Hz – This is an audible tone used to represent a logical 1 in the binary code word.

Each message starts with a 4-bit word and ends with a 4-bit word. The binary coding which has been selected for each type of message used in the HAIR system including the end of message code is given in Table 1.

Table 1. Assignment of Digital Tone Codes

Vehicular Emergency	1	0	1	0	or	0	1	0	1
Fixed Emergency	0	0	0	0					
Traffic Advisory	1	0	0	1					
Trip Information	1	1	0	0					
Channel 1	0	0	1	1					
Channel 2	0	1	1	0					
End of Message	1	1	1	1					

The fourth bit is for (even) parity; consequently, each digital word has an even number of 1's.

Advantage is taken of the audible tones to indicate a warning signal to the motorist during reception of a Vehicular Emergency message. For this message the code word 1 0 1 0 is transmitted three times followed by the end of message code 1 1 1 1. This cycle of 16 bits is repeated with uniform timing between the tones. As a result, the alternating (1 0 1 0 1 0, etc.) tones provide a distinct audible warning signal similar to the "siren" on emergency vehicles of Europe.

Typically, the duration of a tone pulse is approximately 170 ms with a quiet period of 120 ms between adjacent pulses. The general format of the digital word is illustrated in Figure 3. Preceeding the four tone pulses in each word is a dual-tone pulse lasting nominally 440 ms. This pulse consists of both tones occurring simultaneously and serves to clear one of the registers in the decoder immediately prior to reception of the 4-bit code word. It can be seen from Figure 3 that the entire digital word has a duration of 1.6 seconds.

3.4 Encoder and Tape Recorder

All signals for the developmental HAIR system originate with the encoder and consist of a subaudible tone, two audible tones for digital coding, and a voice message. Since the HAIR transmission for a given station is normally expected to be repetitive broadcasts of a short message, the encoder has been designed to operate directly into an endless loop tape recorder/playback machine. A photograph of the HAIR encoder and tape recorder is presented in Figure 4.

Technical descriptions of the encoder and tape recorder are given in this section.

3.4.1 Encoder

In meeting the HAIR system requirements (Section 2) the encoder has been designed to provide the following functions:

a. Generate a tone-coded signal which identifies the beginning of a particular designated type of message.

b. Provide, after a message is initiated by tone coding, a voice message with appropriate speech processing.

c. Generate a tone-coded signal which identifies the end of a message.

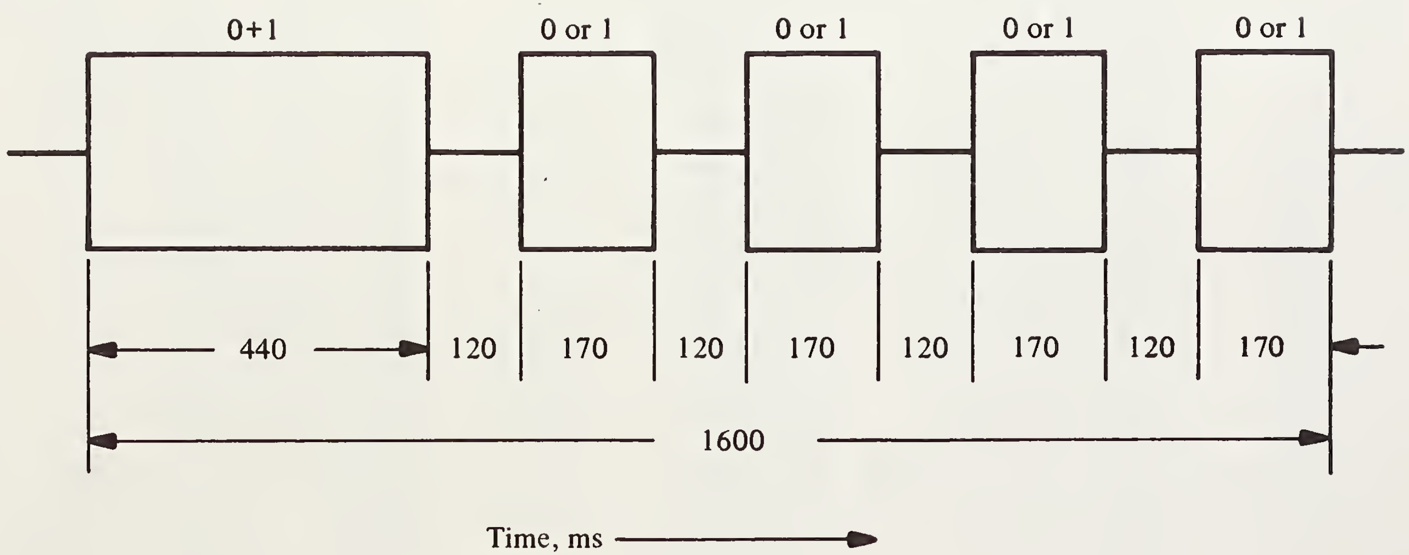


Figure 3. Time Format of Tone Pulses.

Figure 4. HAIR Encoder and Tape Recorder.

d. Generate an audible warning signal for use as the (vehicular) emergency signal.

e. Operate the tape recorder drive during signal generation in order that all of the above signals will be automatically recorded.

f. Generate a continuous subaudible tone signal.

The above functions are accomplished electronically in the encoder. Digital integrated circuits have been utilized throughout for providing all timing and control logic.

The theory of operation of the encoder may be understood with the aid of a functional block diagram shown in Figure 5. The operator selects a message type and depresses the appropriate button or Data Switch. Except for the EMER message, the corresponding 4-bit digital code which is wired into each multiple switch becomes stored in Data Control. The operator then depresses the ENTER button which initiates several timing pulses from the Control Logic. First, a 4-microsecond pulse to Data Control loads the selected binary code into the 4-bit Word Register. At the same time, the 4-microsecond pulse clears the 4-bit Tape Register, enters Tape Control which turns on the tape recorder drive, and enters the Clear Logic circuitry which gates on the 440 ms dual tone (simultaneous 0 and 1) to the output circuits and the Tape Recorder. The Control Logic sends a 1 microsecond pulse to turn on Gated Oscillator 1 750 ms after this initial pulse. This generates a square wave with a frequency of about 5 Hz that enters the three 4-bit registers simultaneously. The 5 Hz frequency shifts the code word out of the 4-bit Word Register into a serial bit stream to the Word Decoder Logic which gates the proper audio tones (852 Hz for a 0, 1477 Hz for a 1). The tone coded word then passes through the output circuitry to the tape recorder. After four cycles of the 5 Hz clock have been received in the 4-bit Stop Register, a stop pulse is sent to turn off Gated Oscillator 1. Also, the four cycles fill the 4-bit Tape Register which, through Tape Control, turns off the recorder drive, enables the push-to-talk switch on the microphone to activate the tape recorder drive, and turns on the Audio Enable light. The encoder is now ready for a voice message. The only code word which can be entered next is END OF MESSAGE and is also generated in the above manner.

The EMER vehicle code (audible warning signal) is derived in a slightly different manner. The operator depresses the EMER button and the ENTER button causing the Control Logic to generate a 4-microsecond initiate pulse as with a regular message. The pulse starts the tape recorder through Tape Control, activates the Clear Logic to generate the 440 ms dual-tone pulse, and turns on Gated Oscillator 2 which is also about 5 Hz. These clock pulses drive both a 16-bit counter and the Emergency Decoder Logic which generate the cyclic pattern of 16 tone pulses. This signal passes through the output circuitry to the tape recorder. The cycle continues indefinitely until the operator manually enters the END OF MESSAGE code.

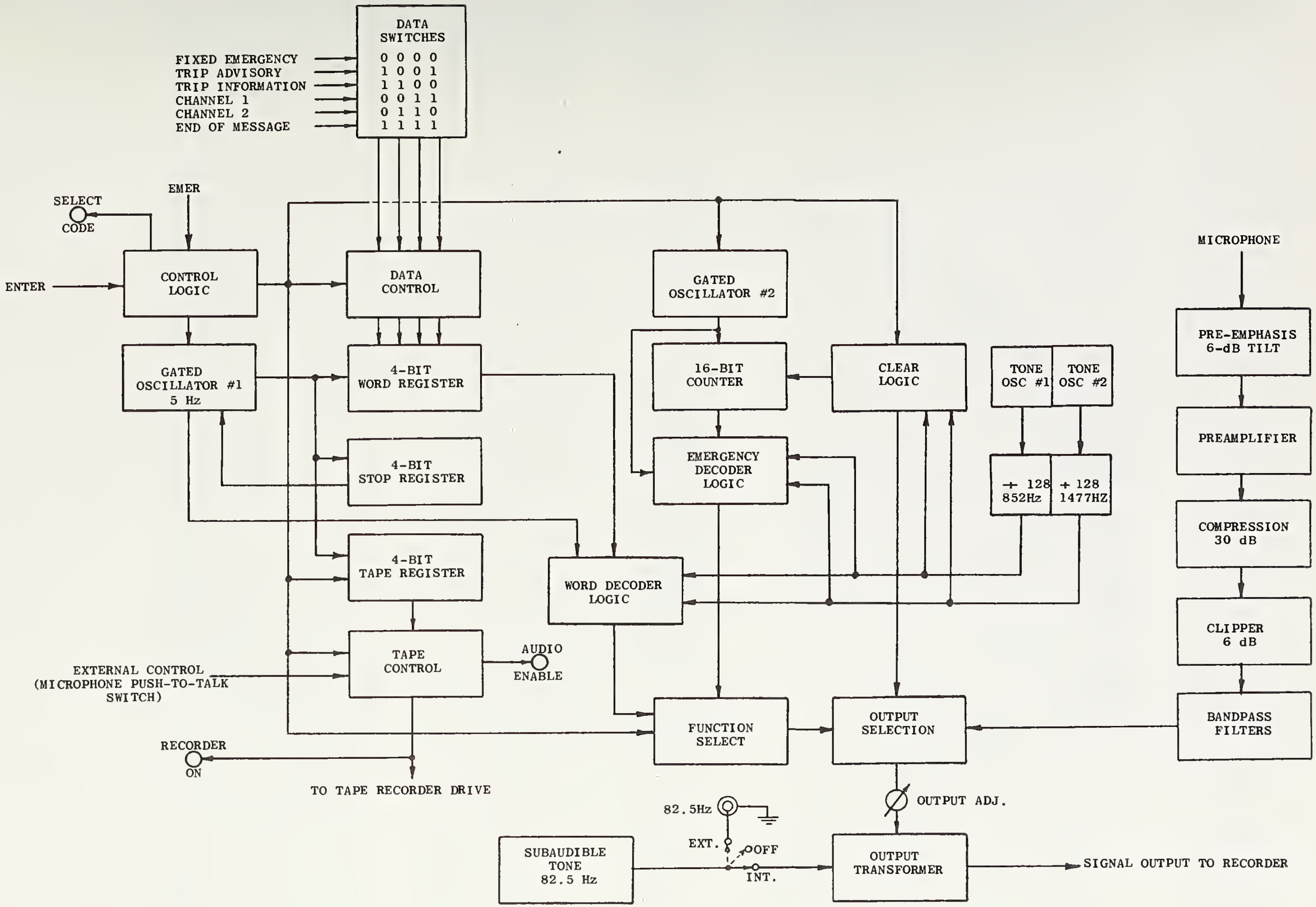


Figure 5. Encoder Functional Block Diagram.

Tone oscillators 1 and 2 operate at frequencies of 109,056 Hz and 189,056 Hz. These are divided down by 128 ($=2^7$) resulting in the two audible tones of 852 Hz and 1477 Hz. These tone frequencies are continually present in the Word Decoder Logic, Emergency Decoder Logic, and the Clear Logic circuits. Each tone is gated to the output circuitry whenever a logical 0 or 1 of a code word is generated and arrives at these circuits.

The speech processor is composed of five elements. First, a pre-emphasis circuit, which is a high-pass filter, provides a 6 dB/octave tilt of the audio frequency spectrum from 300 Hz to 3000 Hz. This helps to preserve the fidelity of high frequency voice signals, particularly a female's voice. This is followed by a preamplifier which increases the amplitude of the microphone signal to the required level. The voice signal then passes through a compression circuit which provides up to 30 dB compression of signal amplitude. The compressor is similar to a fast-acting automatic gain control and helps to maintain the output voice amplitude at a constant average level. A Gain Adjust knob on the front panel controls the desired amount of compression, and a meter on the front panel indicates the amount of compression in dB. Next, a clipping circuit removes high level signal peaks that exceed a preset level. Finally, bandpass filters remove most of the harmonics caused by any clipping. The processed speech signal finally passes through the output circuitry to the tape recorder. Figure 6 presents the overall frequency response of the voice channel through the encoder.

The 82.5 Hz subaudible tone is generated by a vibrating reed oscillator and operates independently of the remaining encoder circuitry. A three-way toggle switch on the front panel permits the subaudible tone to be either connected to an external jack (rear panel), combined with the normal encoder output signal, or turned off.

As can be seen in Figure 5, an OUTPUT ADJ knob on the encoder (rear panel) is for controlling the output amplitude of only the tone-coded and voice signals; it does not affect the amplitude of the subaudible tone. The amplitude of the subaudible tone can be adjusted with a small screw driver through a hole in the rear panel. The relative amplitudes of the tone codes and the voice signals are preset internally and cannot be controlled externally.

The encoder design has included a number of features which are expected to provide a high degree of reliable operation. Functionally, the encoder design has been based on the assumption that personnel operating the controls may be untrained or unskilled. Consequently, the risk of generating incorrect or unintelligible signals has been minimized. For example, to generate a coded message signal two buttons must be depressed – the message select and ENTER. This reduces the chance of an operator sending an incorrect message. Should a wrong message button be depressed inadvertently, the message will not be generated unless the ENTER button is depressed. Thus, the operator can correct his mistake without sending an incorrect signal.

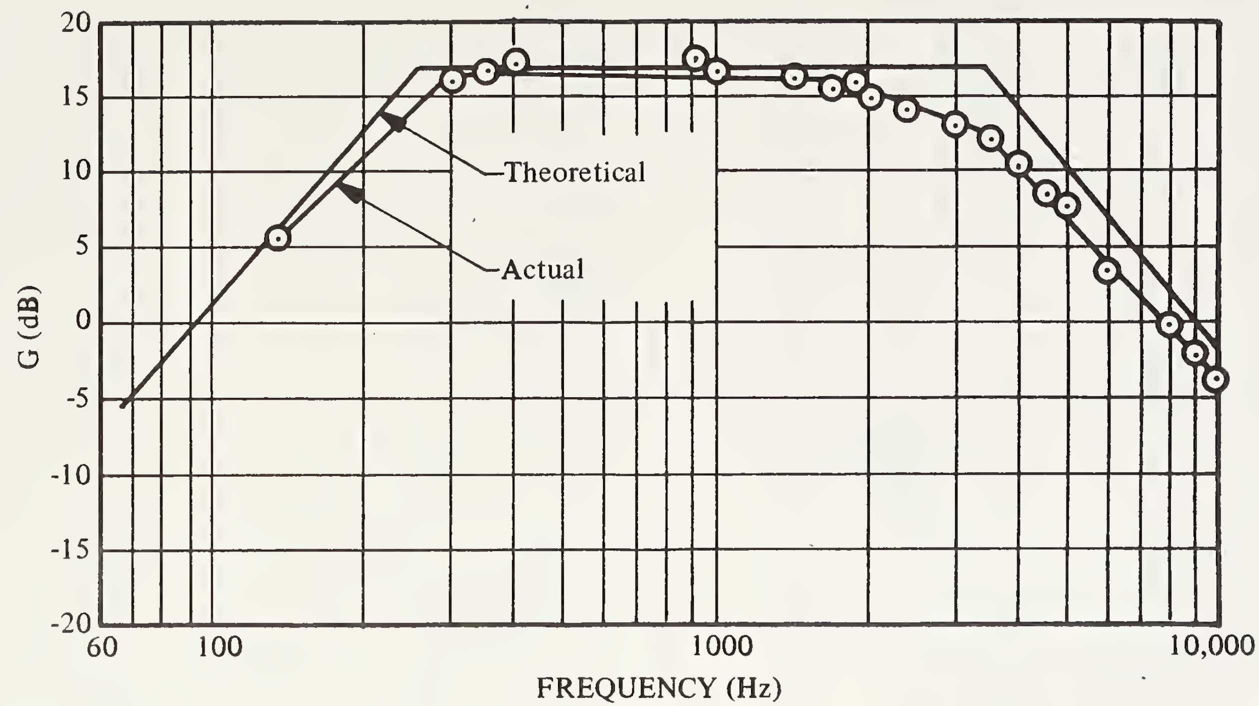


Figure 6. Frequency Response of Speech Processor.

As already mentioned, after the start code of a message has been generated only the END OF MESSAGE is accepted by the encoder. Interlock circuitry prevents any other command from being generated.

Function status lights on the front panel aid the operator in using the encoder efficiently. A SELECT CODE light indicates that the encoder is ready to accept a command to start a message. After a message is selected and entered, the SELECT CODE light turns off and the AUDIO ENABLE light turns on indicating that a voice message can now be entered with the push-to-talk switch controlling the tape recorder. A RECORDER ON light illuminates whenever the tape recorder drive is activated for recording.

The speech processor allows a wide range of voice levels into the microphone to be recorded without distortion. The microphone is a noise cancelling type and requires being held very close to the speaker's mouth to eliminate background noise. Consequently, the voice processor will accept loud or weak signals of a high or low frequency range and provide an output signal at a uniform level for recording without adjustment of encoder controls.

For additional information concerning schematics and wiring of the encoder, refer to Appendix D, Figures 59-63. Setup and operation of the encoder is described in Appendix E.

3.4.2 Tape Recorder

The tape recorder used in the developmental HAIR system is a solid-state commercial Spotmaster model 400A, built by Broadcast Electronics Company, which is designed for use by radio stations to provide spot announcements and commercials. It uses interchangeable tape cartridges, each of which contains a continuous loop of 1/4-inch magnetic tape. Various cartridges have tape lengths that provide running times from 20 seconds up to 31 minutes. Tape speed is 3 3/4 inches per second. A block diagram of the recorder/playback system is shown in Figure 7. The machine has separate recording and playback heads, and has no capability to erase the tape. Erasure is accomplished externally with a bulk eraser on an entire cartridge. Each head is two-track; the upper track is for the message and the lower is for cueing tones that are designed to cause the tape to stop automatically at the start of a message. In order to permit the tape to run indefinitely for use in the HAIR system, the cue signal has to be disconnected at the recording head.

In reference to Figure 7, the operation of the tape recorder and playback machine is as follows. The machine has separate record and playback circuits. The PLAY-RECORD switch on the front panel switches dc power only to the recording circuits; the playback circuit remains active during recording to permit monitoring. The signal to be recorded enters the LINE input jack on the rear panel. A GAIN knob on the front panel adjusts the amplitude as indicated by the VU meter. The signal after amplification goes to the recording head along with a high frequency bias signal. Signals from the playback head are amplified and pass through a LEVEL control potentiometer on the rear panel to the output jack. The output impedance is 600 to 1800 ohms.

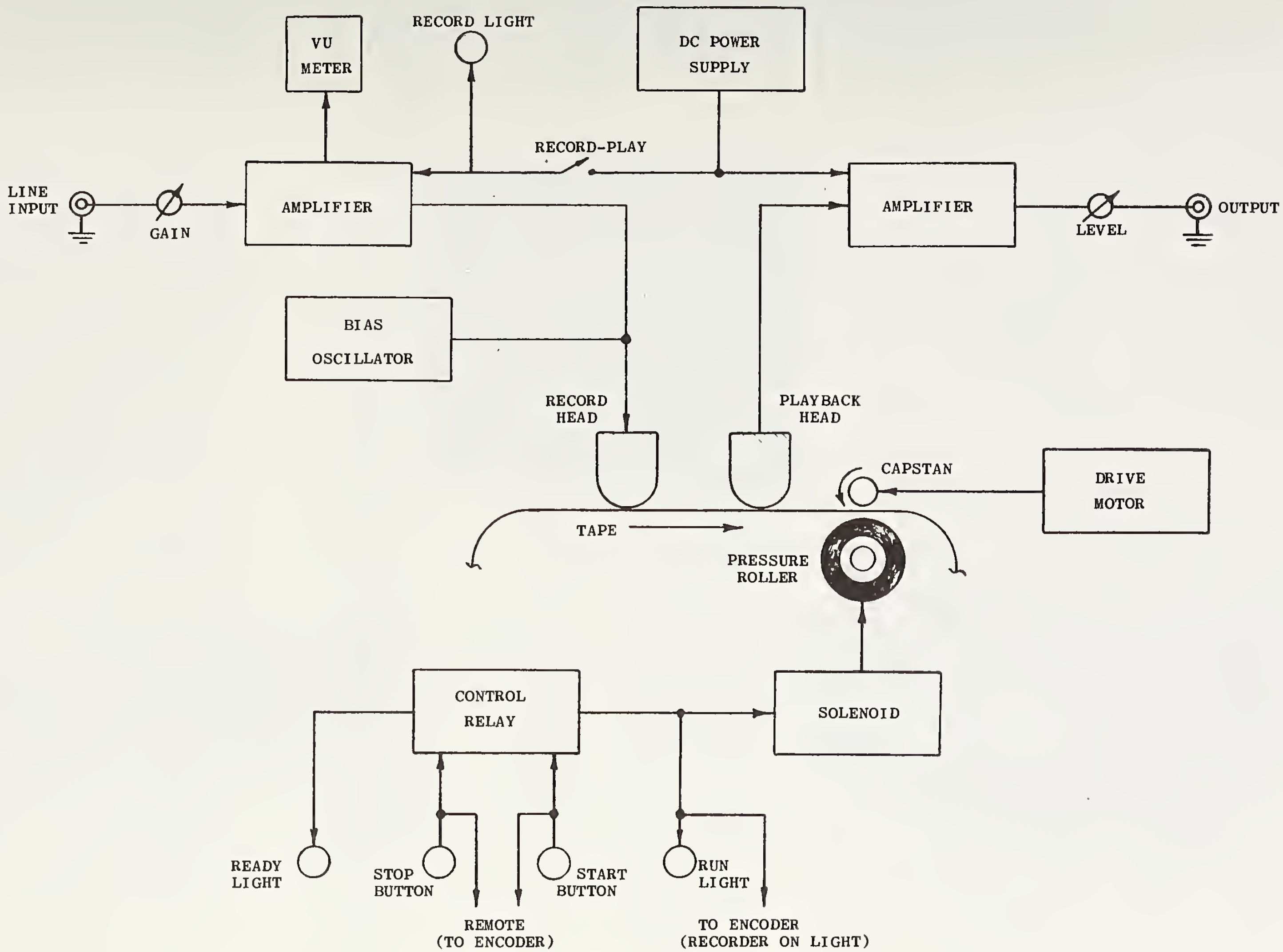


Figure 7. Tape Recorder Block Diagram.

The tape drive mechanism operates as follows. The tape drive wheels consist of a steel capstan and a rubber pressure roller which is mounted on a hinged shaft that swings the roller below the tape deck when a cartridge is inserted or removed. This mechanism is operated by a PLAY-RELEASE lever on the tape deck. When a tape cartridge is inserted, the lever is pushed to the PLAY position. This swings the pressure roller up into a hole in the cartridge case to a position behind the tape about 1/16 inch from the capstan so that the tape does not advance. The lever in the PLAY position also switches on the hysteresis synchronous drive motor that turns the capstan. This is the mechanical standby mode of the tape recorder that permits nearly instantaneous tape startup for either recording or playback. A large solenoid when activated by the CONTROL RELAY moves the pressure roller firmly against the rotating capstan thereby setting the tape in motion. The CONTROL RELAY is activated by a momentary application of electric current by either the START button on the front panel or an external switch connected to the REMOTE octal connector on the rear panel. After the relay is activated, a steady hold-down current keeps the relay activated indefinitely until the STOP button switch (or a remote switch) is depressed, shorting the relay to remove the hold-down current. For the HAIR system the encoder provides the remote tape drive switching which is used during the recording of HAIR messages.

During the time that the CONTROL RELAY is not activated a READY light on the front panel of the recorder is illuminated. When the relay becomes activated, the READY light turns off and the voltage applied to the solenoid also illuminates a RUN light. This same voltage is also monitored by the encoder through the remote connector and activates the RECORDER ON light on the front panel of the encoder.

Schematic diagram of the recorder is shown in Appendix D, Figure 64. Information concerning setup and operation is contained in Appendix E.

3.5 Receiver and Decoder

A photograph showing the three HAIR receivers developed for this program is presented in Figure 8. Each receiver contains essentially identical receiving and decoding circuitry. The functional requirements of the HAIR receivers have already been discussed in Section 2.0, System Requirements and Specifications. Briefly, these may be restated as follows.

The HAIR receiver must respond only to the coded signal transmissions that are generated by the HAIR encoder and to provide a clear, audible output of a HAIR message when received. Only those messages having priority equal to or higher than that selected by the motorist will become audible. With the Adaptor and Integrated units the auto radio is to be automatically muted during audible reception of a HAIR message. The reception of an emergency message will cycle indefinitely; however, traffic advisory and trip information messages will be received through one cycle only before automatic lockout prevents further audible reception. This lockout can be reset manually by depressing the channel select button on the receiver. The audible message should commence only at the beginning of a message cycle and end only at the completion of the cycle. Interruption in the middle of a message should be avoided unless, of course, the receiver leaves the radio transmission zone.

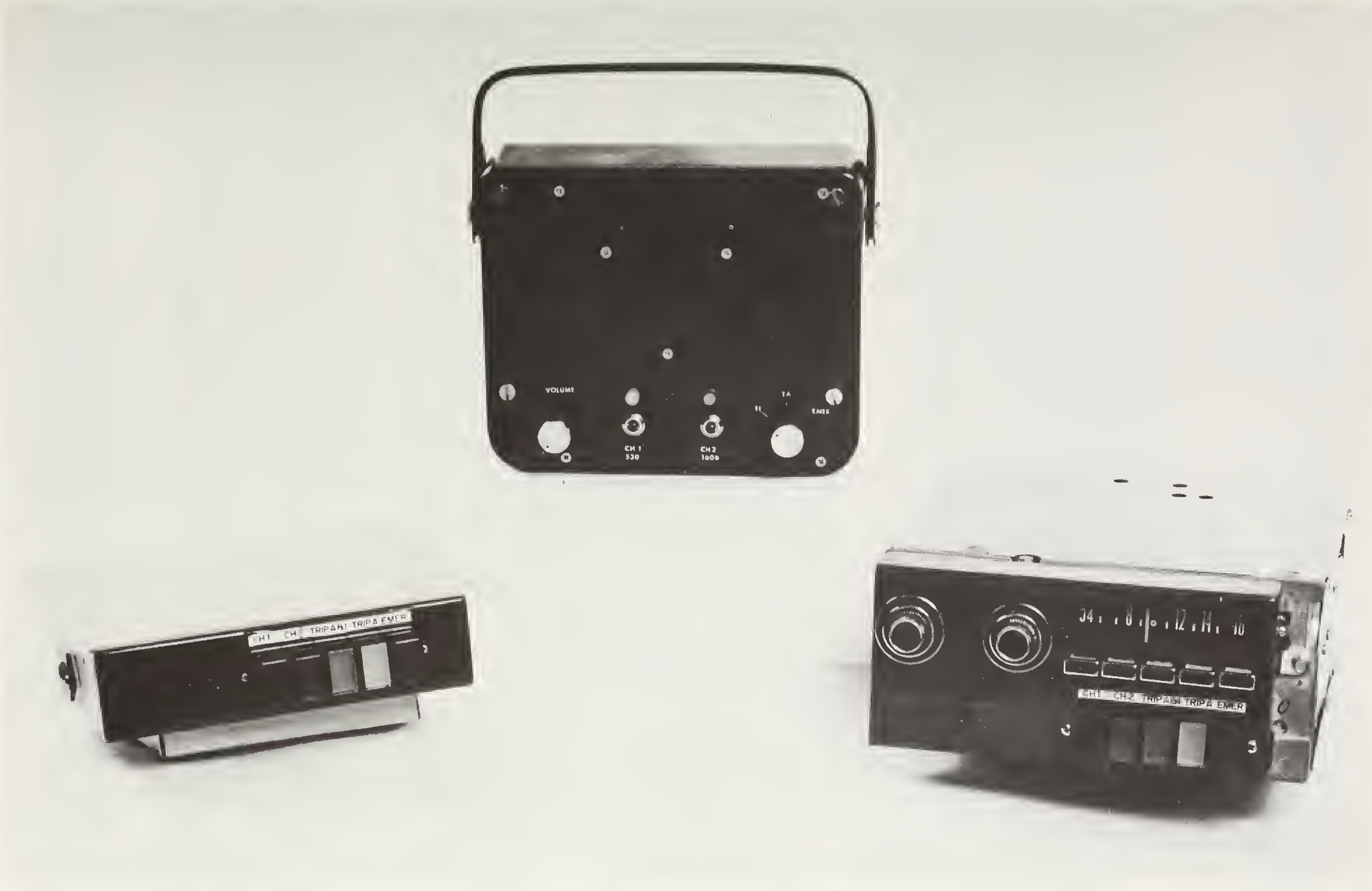


Figure 8. HAIR Automatic Receivers.

The receiving and decoding circuitry are each on separate printed circuit boards and are entirely solid state. The theory of operation of each is presented in the following subsections.

3.5.1 Theory of Receiver Operation

The HAIR receiver is a fixed tuned, dual channel, single conversion, crystal controlled AM receiver. A block diagram of the receiver is shown in Figure 9. For the Adaptor and Integrated units, the antenna input connects to the normal automobile antenna. A pair of traps in the antenna line tuned to each HAIR channel frequency isolates the HAIR radio from the automobile radio at these frequencies. The Portable receiver contains a ferrite stick loop antenna for each channel and, thus, has no traps. The antenna signal enters both RF channels; however, only one channel can be active at a time. Each channel contains four resonant tuned tank circuits and a field-effect transistor amplifier. Channel switching is accomplished by lowering the transistor bias below cutoff for the unwanted channel.

The RF signal is then mixed with the appropriate local oscillator frequency to result in an IF of 2.666 MHz. One crystal oscillator at 4.272 MHz is used to provide the mixing frequencies for both channels to obtain the IF. For channel 2, the 1.606 MHz beats directly with the crystal frequency to give a difference frequency of 2.666 MHz (IF). For channel 1, the crystal frequency is divided by two giving 2.136 MHz which gives a sum frequency of 2.666 MHz when mixed with 530 kHz. Thus, when channel 2 is active the crystal frequency enters the mixer directly, but when channel 1 is active the Divide by 2 Logic is used to provide the correct mixing frequency.

The IF circuit contains three resonant tuned stages. Automatic gain control (AGC) is derived from the IF section and provides a varying dc bias level to the field effect transistor in each channel. The IF signal is then demodulated by a diode envelope detector. The resulting audio signal is split into four paths. Three paths enter tone decoders to extract the audio tone information, and the fourth is the audio output signal which becomes amplified and is switched to the speaker when an appropriate message is received.

Each tone decoder is an integrated circuit containing a phase-lock loop adjusted to capture one of the three tone frequencies. The output level from a tone decoder is +12 volts when unlocked and 0 volts when locked onto a tone frequency. Consequently, the output from the subaudible tone decoder (82.5 Hz) is a dc level at +12 volts or 0 volt depending on whether or not the signal is present and being captured by the tone decoder. Also, the tone decoders for the logical 0 (852 Hz) and logical 1 (1477 Hz) tones generate a rectangular pulse (at 0 volt below 12 volts) each time the digital tones are received and captured by the decoders.

The signals from the tone decoders represent the output signals from the receiver circuit board and are the input signals to the Decoder circuit board discussed next.

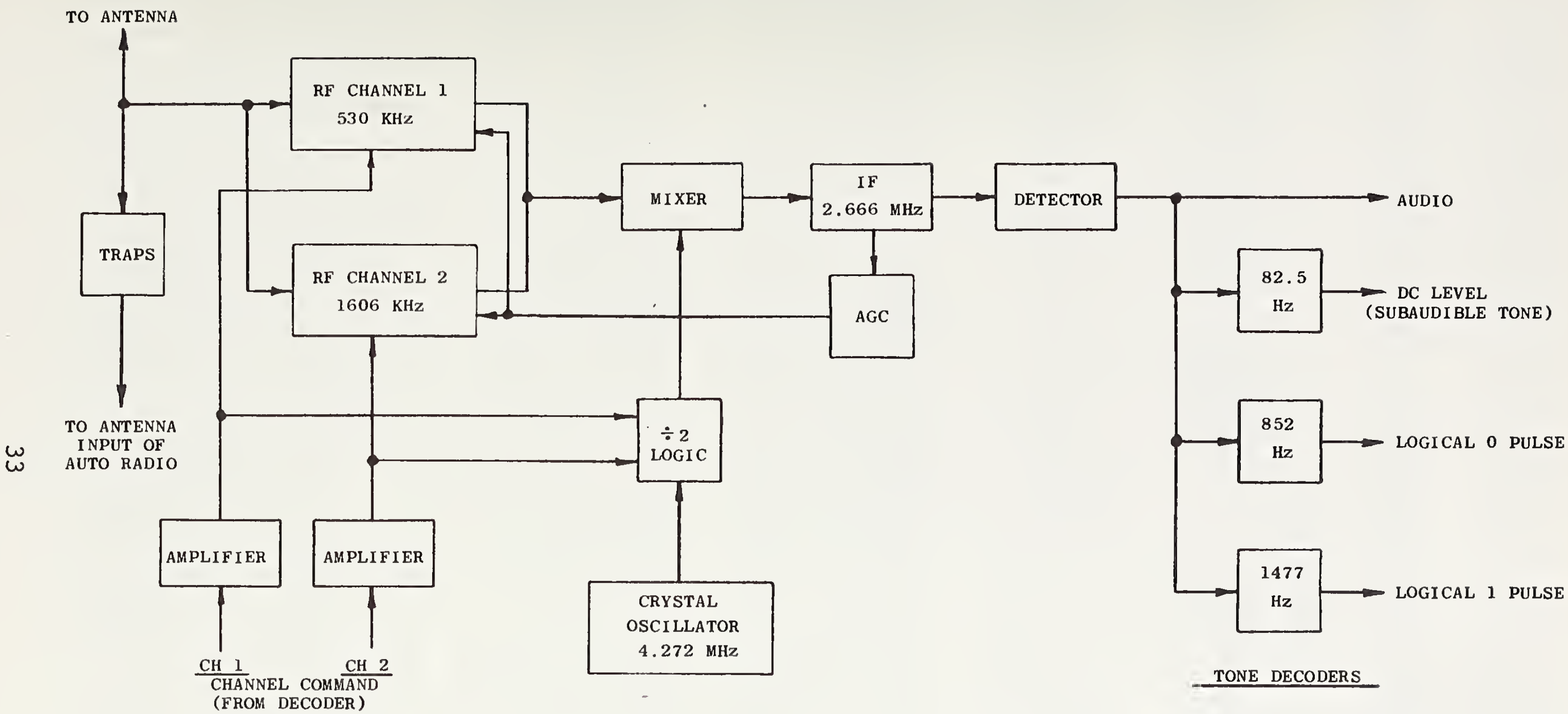


Figure 9. Receiver Block Diagram.

It should be noted that the Mixer, IF, Detector, and AGC circuits in each receiver are all contained within one integrated chip RCA CD3088E which functions nearly as a complete AM receiver.

Wiring diagrams and schematics for each receiver are contained in Appendix D, Figures 66-72. Installation and operation of the receivers are covered in Appendix E.

3.5.2 Theory of Decoder Operation

The primary function of the Decoder is to turn on the speaker whenever an appropriate HAIR message is received and simultaneously to mute the auto radio to ensure that the motorist will hear the message. A block diagram of the Decoder is shown in Figure 10.

Although the Decoder has been designed to process a specific digital code format, a number of features have been incorporated into the Decoder design to minimize disturbances from noise spikes and interfering signals which may also be received, detected, and somehow appear at the Decoder input.

With reference to the block diagram of Figure 10, the processing of the digital codes through the Decoder may be explained as follows. The digital information to be processed appears in two binary pulse lines, a logical 0 and a logical 1. These two lines are complementary; that is, except for the dual-tone burst, a 0 does not occur when a 1 occurs, and vice versa. Thus, the message code can be found in each of the logical 0 or logical 1 lines. Arbitrarily, the logical 0 input provides the binary word data to the Decoder. The four bits of data enter the Information 4-Bit Shift Register prior to processing.

The Center Sample circuit examines a short sample of either the logical 0 or logical 1 pulse at a time somewhere near the center of the pulse. If the level is correct, then a true data pulse is considered to have been received. This center sampling is accomplished as follows. The pulse rise time initiates a 70 ms delay circuit which results in a sample near the middle of the pulse. This delay time, however, is generally longer than the duration of noise spikes. Thus, the "center" sample that is initiated by a noise spike will usually not result in a correct sample level, and no data output occurs from the Center Sample circuitry.

Upon receiving valid data pulses, the Center Sample sends this detection information as a series of timing pulses to the Input Clock circuits which provide the clock pulses for both shift registers. In a sense, each data bit, whether a 0 or a 1, clocks itself into the Information Shift Register. Simultaneously, logical 1 bits (derived from the +12-volt input) are shifted into the Strobe Register. The filling of the Strobe Register with four 1's signifies that four data bits have been shifted into the Information Register. At this time a strobe pulse advances the data to three locations: the Parity Check, Address Logic, and Reset Logic. The Parity Check circuits examine all four bits and if parity does not check, the data word is rejected and the decoder is reset. If the message transmission appears true, the three-bit data word in Address Logic is then advanced by another strobe pulse to Address Storage. Once the data have advanced to Address Logic or beyond, it cannot be

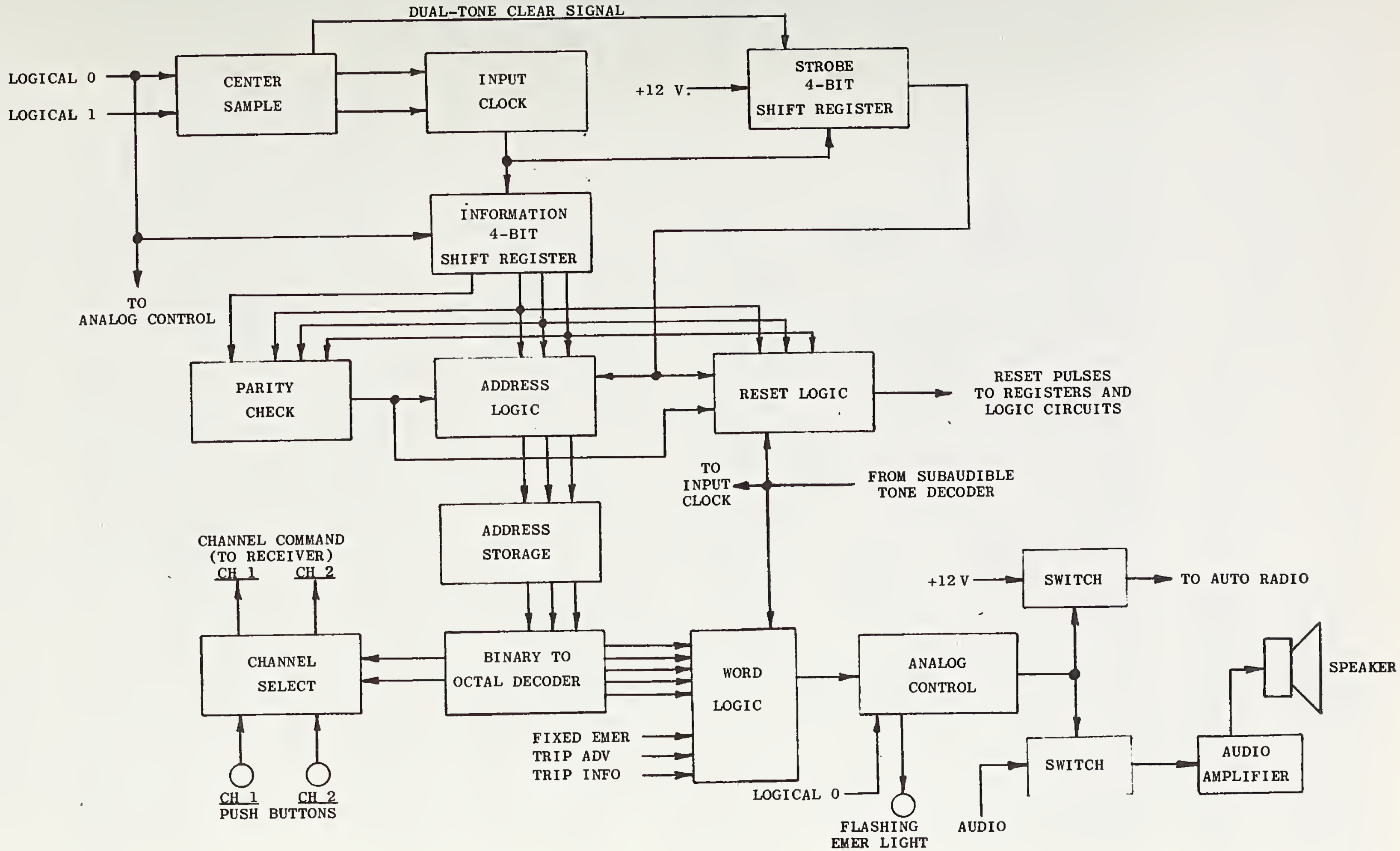


Figure 10. Decoder Block Diagram.

affected by any input signals to the Decoder. This feature ensures that incoming noise will not cause a code word to be disturbed during a voice message and thereby result in an untimely resetting of the Decoder.

The End of Message code is detected by the Reset Logic circuits and causes, by several reset pulses, the Decoder to terminate operation.

When the code word reaches Address Storage, the Binary to Octal Decoder converts the three bit code into an octal number which activates only one of seven output lines. (Although eight outputs are possible, one corresponding to the End of Message code 1 1 1 1 will not appear in Address Storage.) The active outline line then triggers a corresponding function. The codes for switching a channel will activate Channel Select sending an appropriate Channel Command signal to the receiving circuit board. The remaining codes which are related to an audible message are processed in Word Logic along with the message priority level selected by the front panel buttons. If the coded message priority is equal to or higher than that selected by the motorist, the Word Logic will then give the final command signal to Analog Control to mute the auto radio and to connect the HAIR audio signal to a speaker.

It should be noted that the 12-volt switch to the auto radio shown in Figure 10 pertains only to the Adaptor Unit. The audio switch to the amplifier and speaker occurs in all three receiver units. However, with the integrated unit, the audio amplifier and speaker are part of the auto radio. The switch connects the audio signal from either the auto radio or HAIR radio to the amplifier.

The dc voltage level from the subaudible tone decoder connects to several circuits in the Decoder. The continual presence of this tone is necessary for the Decoder to function, and even a momentary loss of this signal results in the resetting of many Decoder circuits and the corresponding loss of an audible HAIR message, if present. The message cannot be heard again until the subaudible tone returns and a message start code is received.

The logical 0 pulse train during receipt of a vehicular EMER signal is used to flash the red light (light emitting diode) on the front panel.

A schematic of the decoder board is contained in Appendix D, Figure 65.

3.6 Transmitter

The transmitters used in the developmental HAIR system are shown in the photograph of Figure 11. These transmitting units were manufactured by PRF, Inc., Lansdale, Pennsylvania, and purchased from CCA Electronics Corporation, Gloucester City, New Jersey. Each transmitter is solid state, fixed tuned, crystal controlled, AM, with variable modulation and output power controls. The average output power can be adjusted from zero to more than 10 watts of unmodulated carrier into a 50-ohm load.

Figure 11. HAIR Transmitters.

The theory of operation of each transmitter may be explained with the aid of the block diagram shown in Figure 12. A crystal oscillator operates at the transmitting frequency. This signal is amplified and passes to the amplitude modulation circuitry. This circuit not only places the modulating signal onto the carrier but also provides the adjustment of average carrier amplitude. These controls are produced in the following manner. In the modulation circuit the carrier signal passes through a series diode. The amplitude of the signal leaving the diode is proportional to the back bias level applied to the diode. This bias voltage is supplied from the output of an operational amplifier and consists of both dc and ac voltages. The dc level is derived from the RF OUTPUT potentiometer on the front panel and establishes the average carrier amplitude at the diode output. The ac component is the audio modulating signal and provides a variation in bias level on the diode to result in an amplitude modulated carrier signal. Two modulation input connectors are located on the back panel. One input labeled RCDR is a 600-ohm input line for signals from the recorder output. The other connector labeled TONE is available for the subaudible tone on a separate line from the EXT output jack on the rear panel of the Encoder. The modulating signals pass through an audio transformer that provides both dc isolation and impedance matching, through the variable gain MODULATION potentiometer on the front panel, through a capacitor and to the input of the operational amplifier.

It can be seen that the above modulation technique does not result in constant percentage modulation when the power control is varied. The ac and dc bias components are controlled independently; however, the percentage modulation is determined essentially by the ac to dc ratio. Thus, for a given ac amplitude, a change in the dc amplitude (or transmitter power) also changes the ac/dc ratio (or percent modulation). Consequently, adjustments of the RF OUTPUT level generally require readjustment of the MODULATION control if a fixed percentage modulation is to be maintained.

The modulated carrier signal from the modulator then passes through the DRIVER amplifier and the POWER AMPLIFIER to the OUTPUT TUNED CIRCUIT. It may be noted that the carrier signal does not become sinusoidal until reaching the final stages which are sharply tuned to the desired fundamental frequency. The primary purpose of the output circuit is to provide impedance matching between the power amplifier and a 50-ohm load. A trimmer capacitor in the OUTPUT TUNED CIRCUIT allows tuning readjustment to eliminate harmonic distortion in the output signal that can arise from mismatched loads or overheating.

A sample of the output signal is attenuated and detected and provides a reference level of output power for the operational amplifier. This feedback circuit helps to obtain reliable control of transmitter power.

Another sample of the output signal connects through a resistor to a BNC connector on the front panel to permit monitoring the signal on an oscilloscope. The output signal is always monitored with an oscilloscope during tests to ensure that the carrier is undistorted and to measure the carrier amplitude and percentage modulation.

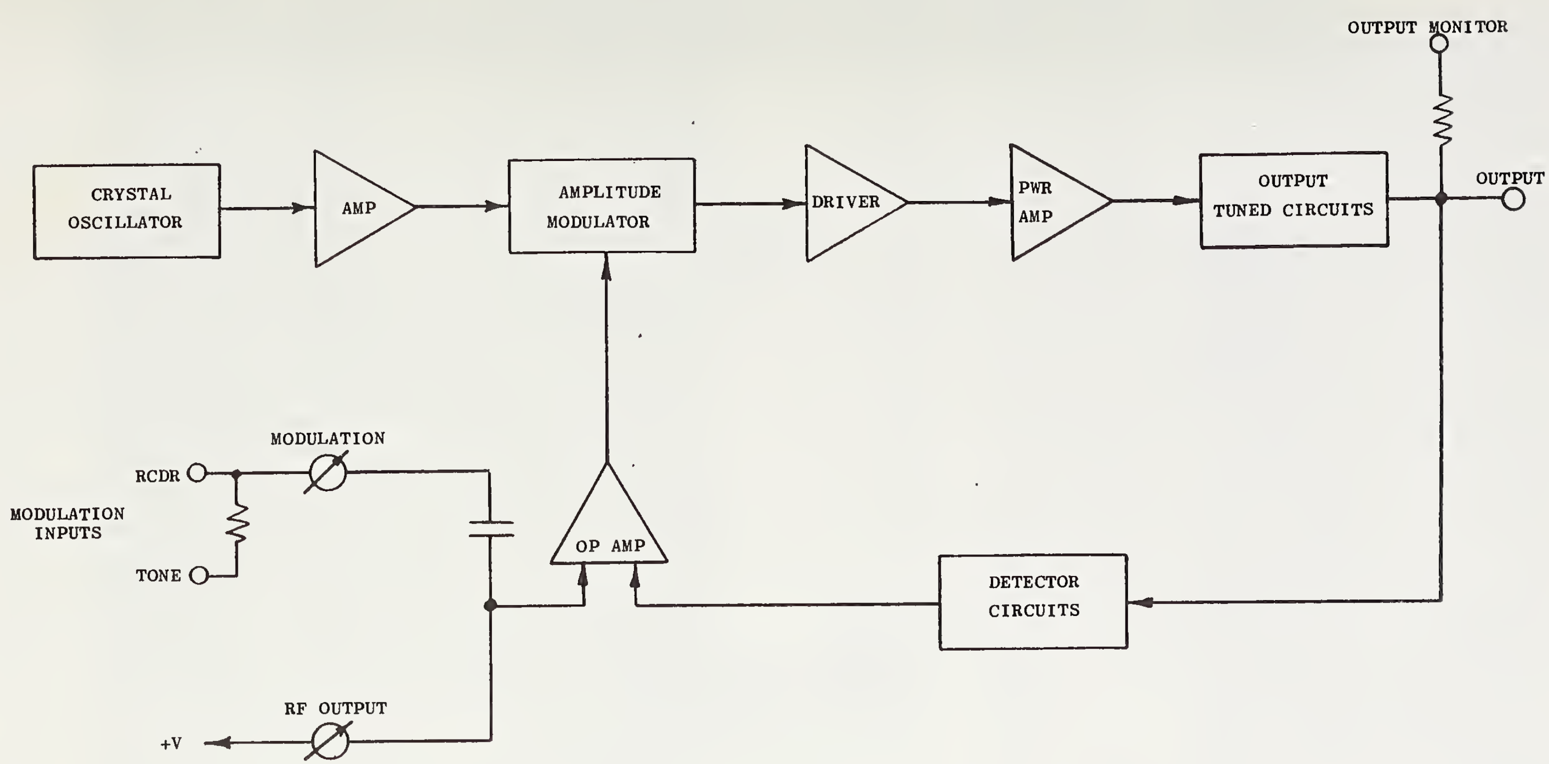


Figure 12. Transmitter Block Diagram.

Schematics of the transmitters including all Atlantic Research modifications are contained in Appendix D, Figures 56, 57 and 58. Setup and operation of the transmitters are described in Appendix E.

3.7 Antenna Systems

The requirement of the HAIR radiation system is that it provides adequate field strength coverage throughout a continuous section of a highway and over all lanes carrying traffic in at least one direction so as to result in satisfactory operation of the HAIR receivers throughout the message zone. Where possible, the radiating system should provide a minimum amount of radio fields outside the desired coverage zone.

Two basic types of radiation systems were examined for use with the developmental HAIR system. One type employed vertical monopoles or whip antennas, and the other utilized a cable antenna. A description of each of the antenna systems tested in this project is given in this section. The experimental results of these tests are presented in Section 4.0, System Tests and Evaluation.

Whip antennas were used for nearly all HAIR system testing. The cable antennas were tested briefly at the end of the program to determine their compatibility as radiating elements in the HAIR system.

3.7.1 Whip Antennas

Three fiberglass whip antennas (Shakespeare Wondershaft Style 207-B) were purchased through Lafayette Radio. A photograph of one of these antennas is given in Figure 13. These whips, designed for operation at approximately 2 MHz, are 18 feet long and consist of two equal-length sections. The conducting element in the lower section is helically wound to provide electrical loading or lengthening of the antenna. The top section is a straight vertical conductor. The conductors in each whip are covered with fiberglass which provides a rugged, weatherproof exterior. The lower section is rigid, but the upper section is flexible and is designed to withstand high winds.

Each whip antenna was mechanically supported at the lower end to a rigid steel post. One or more ground rods 3 to 8 feet in length were driven into the ground around the base of each antenna. These rods were then electrically tied together forming the ground terminal against which the whip antenna was fed by the coaxial transmission line.

Matching transformers were constructed for each antenna to provide impedance matching between the 50-ohm coaxial transmission line and the antenna impedance at each of the two channel frequencies. Figure 14 shows a detailed photograph of the manner in which the matching unit and electrical connections were arranged at the base of a typical whip antenna installation. Each matching network consists simply of an adjustable inductance which is tuned for series resonance with the antenna; that is, the inductive reactance cancels the capacitive reactance of the antenna resulting in a purely

Figure 13. HAIR Whip Antenna.

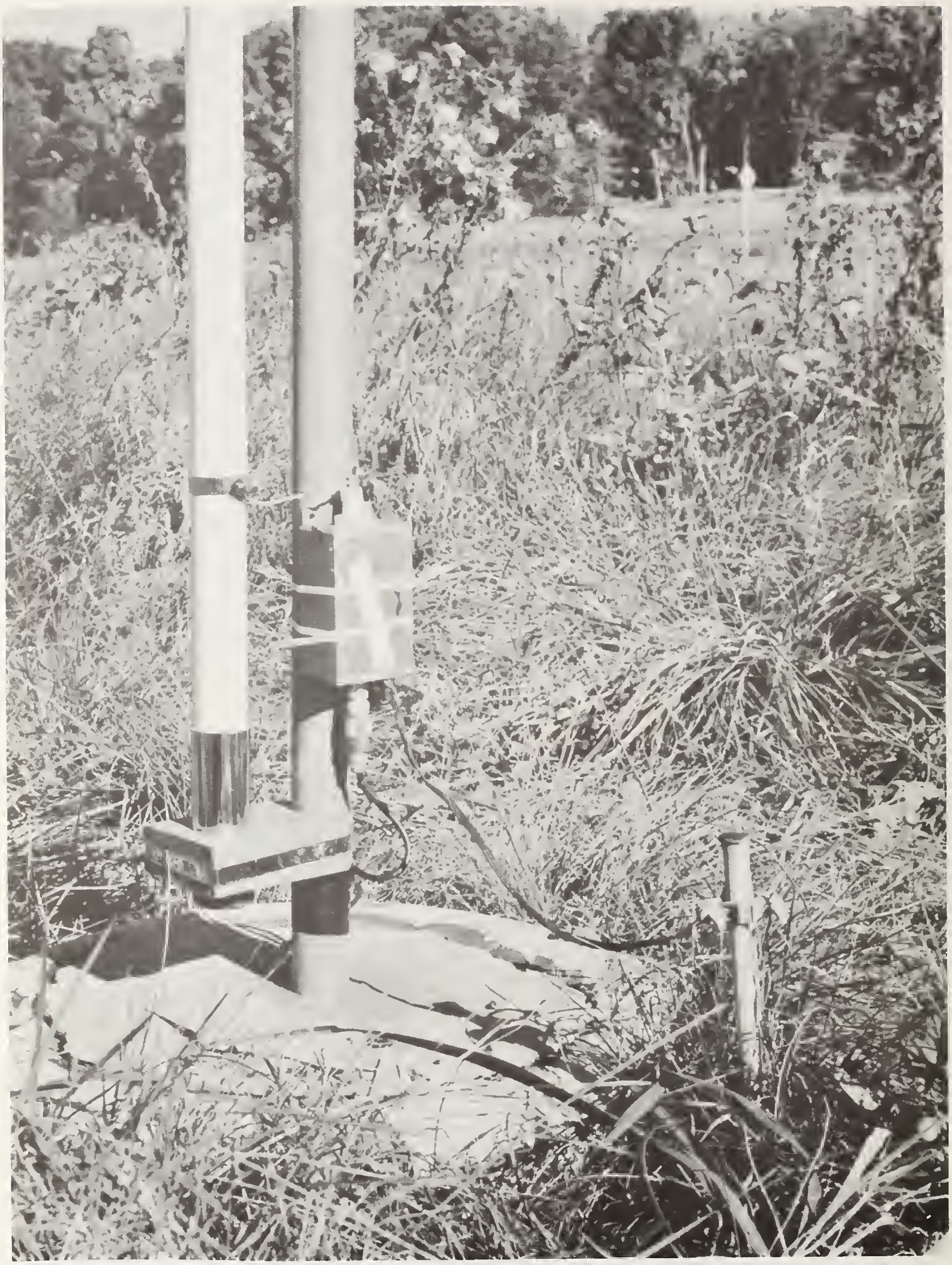


Figure 14. Antenna Base and Matching Network.

resistive load. At both frequencies this resulting resistance is sufficiently near 50 ohms so that no impedance transformation is necessary. The Q of the antenna/matching network circuit has been designed to be less than 100 to provide tuning stability with normal changes in ambient temperature and ground conductivity.

Measurements of the antenna base impedance with and without matching are given in the table below.

Table 2. Base Impedance of Whip Antennas, ohms.

	Antenna 1	Antenna 2	Antenna 3
530 kHz, no matching	13 – j5490	26 – j5720	10 – j5500
530 kHz, with matching	57 + j0	70 + j0	54 + j0
1606 kHz, no matching	16 – j1520	20 – j1560	26 – j1440
1606 kHz, with matching	28 + j0	32 + j0	38 + j0

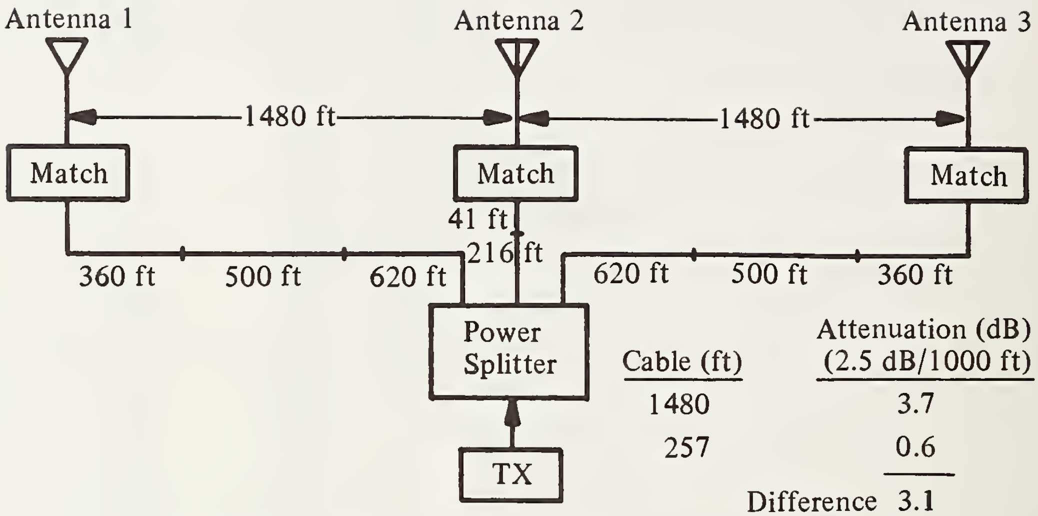
The resulting values of VSWR at the antenna base with matching are 1.4 at 530 kHz and 1.8 at 1606 kHz. These represent approximately 0.1 dB and 0.4 dB, respectively, of power lost due to mismatch reflection.

Two arrangements of whip antenna systems were examined. One system utilized only one whip antenna, and the second system employed an array of three whips equally spaced in a straight line. From an analysis of the radiation pattern resulting from three isotropic radiators at various spacings and relative phasings, it was determined that near optimum coverage could be obtained over the 4,000-foot message zone with the three antennas arranged as follows:

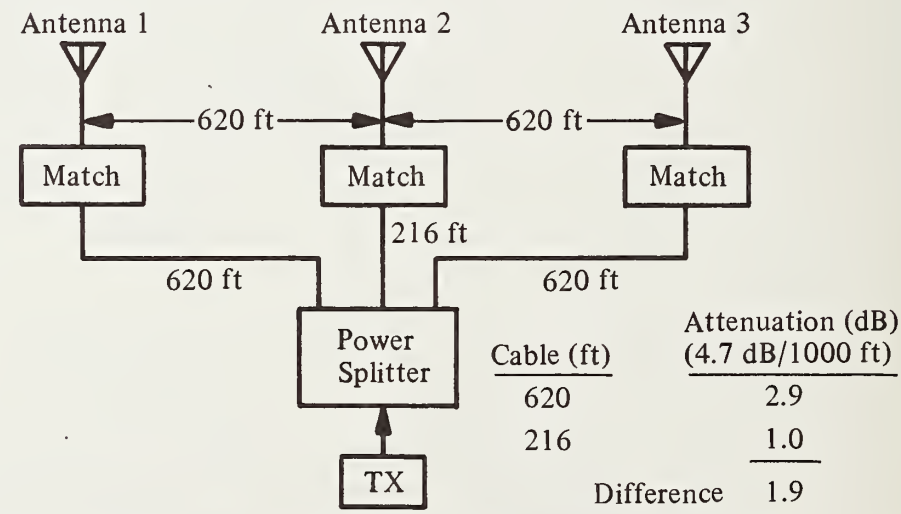
At 530 kHz:	0.8λ (1480 feet) spacing between antennas. All three antennas fed in phase.
At 1606 kHz:	1λ (620 feet) spacing between antennas. All three antennas fed in phase.

These results were based on the whip antennas located 50 feet from the edge of the roadway.

The arrangement of cable lengths used to achieve the antenna arrays specified above are illustrated in Figure 15. The manner in which the total lengths of cable between each antenna and the transmitter were determined may be explained as follows. Clearly, if the cables to the three antennas are of equal length the antennas would be fed in phase, regardless of the cable length used. Further, this in-phase relationship is not altered if one of the cable lengths is decreased (or increased) by an integral number of electrical



Antenna Spacings and RG-58 Cable Connections for 530 kHz



Antenna Spacings and RG-58 Cable Connections for 1606 kHz

Figure 15. Antenna Array Spacings and Cable Lengths.

wavelengths. Consequently, with the transmitter located close to the center antenna, equal length cables were connected to Antennas 1 and 3, and the cable to the center Antenna 2 was reduced in length by one electrical wavelength. The type of cable used was RG-58/U coaxial cable with a polyethylene dielectric. Since the velocity of propagation in this cable is 65.9 percent of the speed of light, the electrical wavelength in the cable is 0.659 times the corresponding wavelength in free space. These values of wavelength are the following:

Frequency (kHz)	Wavelength in free space (ft)	Wavelength in cable (ft)
530	1857	1224
1606	613	404

Power to the three antennas is provided by a three-way power splitter at the transmitter. The electrical circuit of the power splitter, also purchased from CCA Electronics Corporation, is presented in Figure 16. It can be seen that between the input and output transformers is a parallel resonant tuned circuit; consequently, the value of the capacitor must be changed according to the channel frequency. The insertion loss of the power splitter is less than 0.5 dB.

Cable attenuation accounts for some power loss to the antennas. Based on a cable attenuation of 2.5 dB per 1,000 feet at 530 kHz for RG-58 the cables attenuate the signal by 3.7 dB to Antennas 1 and 3, and by 0.6 dB to Antenna 2. Note that the power delivered to Antennas 1 and 3 is 3.1 dB less than the power delivered to the center Antenna 2.

Similarly at 1606 kHz, the cable attenuation is 4.7 dB per 1,000 feet. This results in signal attenuation of 2.9 dB to Antennas 1 and 3, and 1.0 dB to Antenna 2. In this case the power delivered to Antennas 1 and 3 is 1.9 dB less than the power delivered to Antenna 2.

Field intensity patterns for the one antenna and three antenna systems have been calculated representing the distribution of field strength along the highway through the 4,000-foot message zone. These calculations were not based entirely on theoretical considerations since the radiation efficiency of a short vertical monopole over real ground is subject to considerable uncertainty. Ohmic losses in the matching network and the antenna, and ground losses account for the principal power loss in such an antenna system. Measurements of field strength from one whip antenna have given the following results:

At 530 kHz:	6.55 mV/m at 200 feet for 1 watt delivered to matching network.
At 1606 kHz:	23.5 mV/m at 200 feet for 1 watt delivered to matching network.

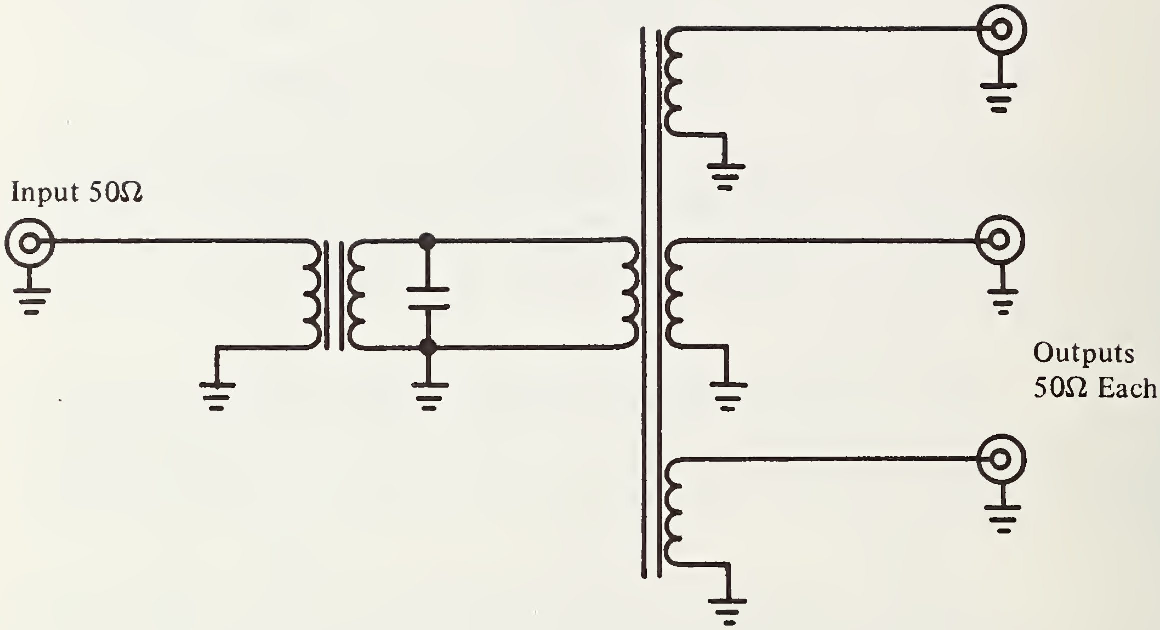


Figure 16. Electrical Circuit of Power Splitter.

From these data the overall (power) efficiency of the antennas can be calculated from the equation

$$P_r = \frac{E^2 R^2}{30G}$$

where

P_r = total radiated power in watts

E = field strength in volts per meter

R = distance in meters

G = (power) directivity of antenna = 1.5

The efficiency of an antenna is given by

$$\text{eff.} = \frac{P_r}{P_i}$$

where P_i is the power delivered to the antenna. Substituting the above data into these equations yields the following efficiencies for the whip antenna and matching network:

At 530 kHz:	eff. = 0.35 percent
At 1606 kHz:	eff. = 4.6 percent

Field strength calculations for the whip antennas are based on the following criteria. For distances greater than 0.15λ the field strength varies inversely proportional to distance R. For distances less than 0.15λ the field strength varies inversely with R^3. These criteria were obtained from a consideration of theoretical near field curves for a vertical monopole of length 0.01λ to 0.04λ.

The field strength for a one antenna system is given simply by the above inverse-distance relationships. For the three antenna array, the field strength at each point is the magnitude of the vector sum of the three separate fields, where the vector phase is determined from the relative propagation phase delay of each radiated signal. The resulting calculated distributions of field strength for one antenna and three antennas are presented in Figure 17 for 530 kHz and Figure 18 for 1606 kHz. These curves, which are based on one watt delivered to each antenna, may be compared with actual measured values given in Section 4.0. The calculated field strengths in the above figures were made for points along a straight line 50 feet from the antenna baseline for the single antenna and for distances of 50, 80 and 200 feet for the three antenna array.

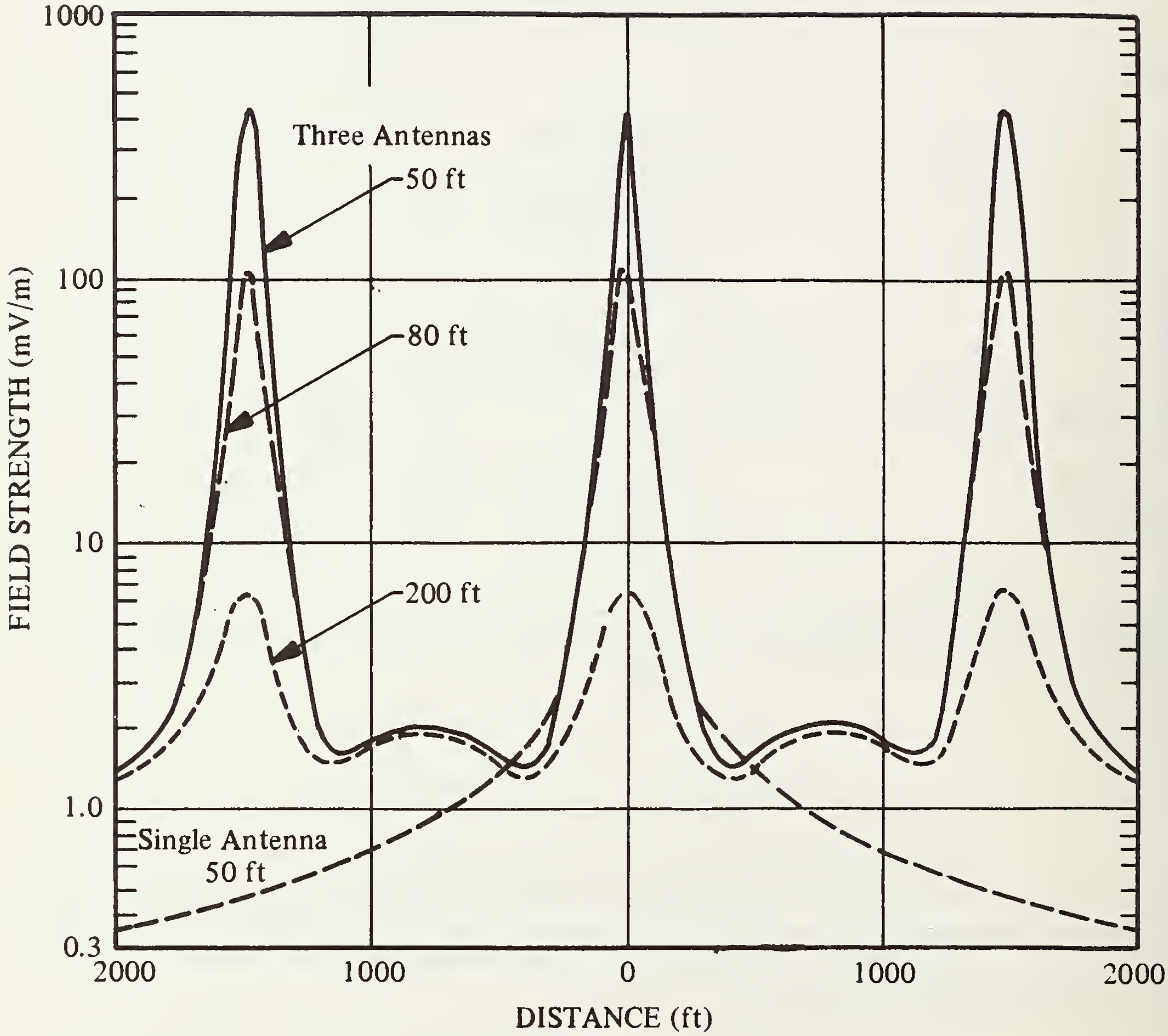


Figure 17. Calculated Field Strength for Whip Antenna Array at 530 kHz.

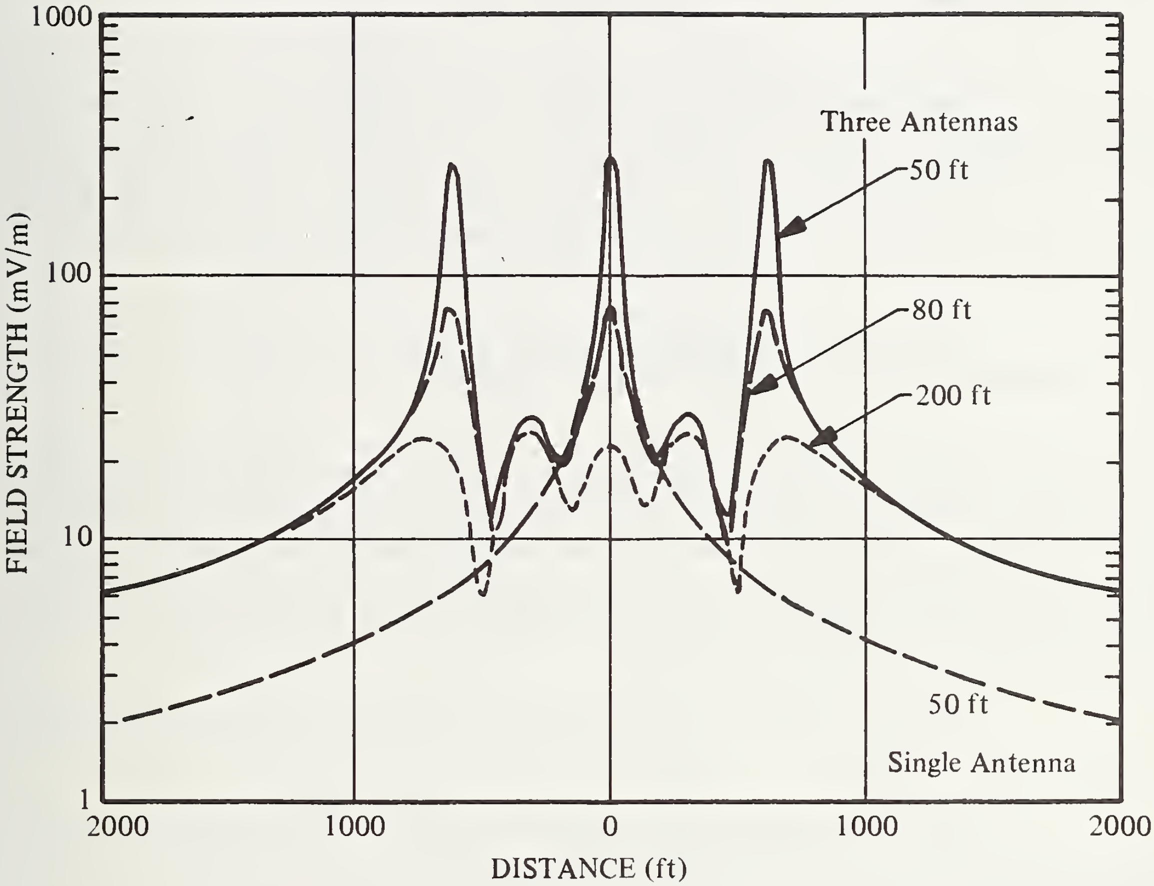


Figure 18. Calculated Field Strength for Whip Antenna Array at 1606 kHz.

3.7.2 Cable Antennas

Two types of buried cable antennas, each 1,000 feet in length, were purchased and tested in the HAIR system. One type was Andrews Corporation RADIAX slotted coaxial cable which is a standard 1/2-inch, foam dielectric HELIAX coaxial cable with slots cut through the outer conductor along one side of the cable. This cable has a brown polyethylene jacket with an outside diameter of 0.620 inch. The weight of the cable is 0.185 lb/ft. Standard foam HELIAX cable connectors and splices can be readily used with the RADIAX cable.

The cable impedance is 50 ohms and required the use of a 50-ohm termination at the far end of the cable to prevent problems with the transmitter due to a highly mismatched load. With power delivered into the terminated cable, measurements of the signal amplitude at each end of the cable indicated that approximately 18 percent of the input power was dissipated within the 1,000-foot section of cable at 530 kHz. Calculations show that approximately 10 percent of the input power was dissipated in ohmic and dielectric losses, and 9 percent of the input power at 530 kHz was radiated.

The results of field strength measurements and HAIR system tests using the Andrews RADIAX coaxial cable are presented in Section 4.0.

The second type of antenna cable examined was manufactured by COM/SCOPE Division, Continental Cable Company, Catawba, North Carolina. The structure of this cable is illustrated in Figure 19 and consists of a small diameter foam coaxial cable at the center with a thin copper ribbon helically wrapped within the outer polyethylene insulating jackets. The signal to be radiated is electrically connected between the helical ribbon and the outer conductor of the coaxial section. Use of the coaxial cable center is extraneous and is not required for radiation.

The outer diameter of the cable is approximately 3/4 inch. Additional data on this cable is unavailable.

The input impedance of the cable (as a radiator) when terminated in 50 ohms was measured to be approximately 50 ohms at 530 kHz and 75 ohms at 1606 kHz. Measurements of the amount of input power dissipated in the cable indicated values somewhat higher than those given above for the Andrews RADIAX cable. The ohmic and dielectric losses of the COM/SCOPE cable (as a radiator) are not known; consequently, the percentage of input power radiated cannot be determined accurately.

It appears that the radiation mechanism for each type of cable antenna is not completely understood, for there are a number of different theories given as possible explanations. In any case, the radiation of energy appears to be due to an electrically unbalanced condition between the conductors and also between each conductor and ground. Following this premise it is not difficult to imagine other possible types of "leaky"

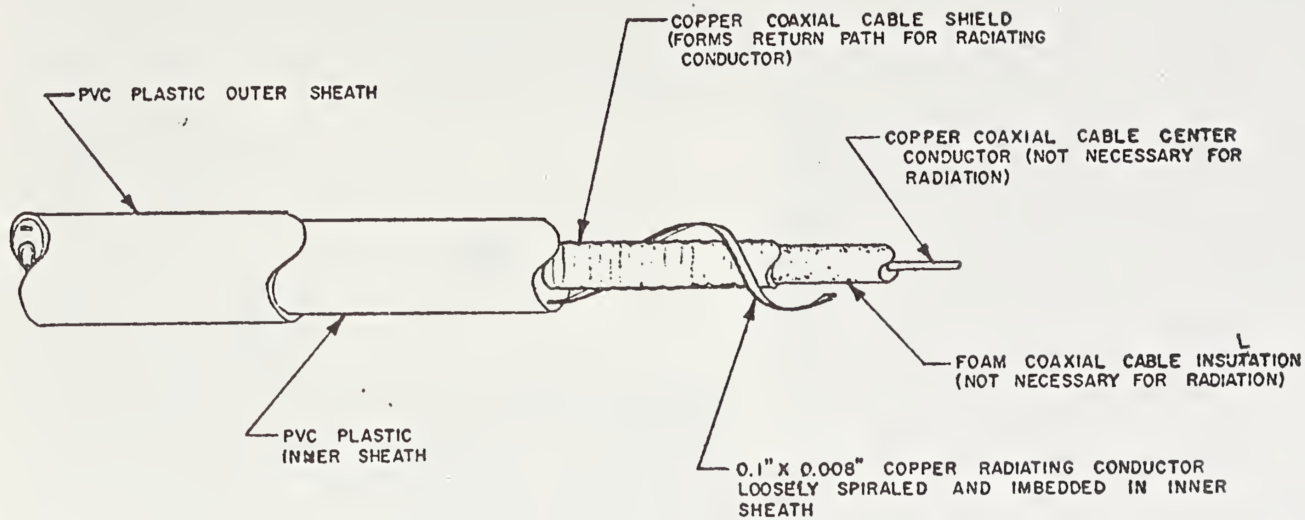


Figure 19. COM/SCOPE Buried Cable Antenna.

cable antennas involving certain arrangements of two conductors. Another class of cable antenna is the balanced transmission line on the ground. The conductors of this system may straddle the highway to ensure that an electric field is established in the motorist lanes. Closely related to this type is a large loop antenna which may enclose a section of the highway.

It should be noted for the cable antennas examined that measurements of the radiated electric field as received by an automobile whip antenna cannot be properly measured with equipment using a loop antenna. Measurements within 100 feet of the Andrews RADIAX cable revealed that the maximum vertically-polarized field strength at any point using a calibrated loop antenna was always greater than when using a calibrated whip antenna. Further, the field strength measured with a loop antenna appeared to decrease inversely as the square of the distance from the cable, whereas the field strength measured with a whip antenna decreased inversely with distance. Interestingly, the maximum vertically-polarized signal level received at any point with the loop antenna was oriented parallel to the cable. These results are associated with the near field characteristics of this type of antenna and deserve further study.

The results of Atlantic Research Corporation's field tests of all the antenna systems described herein are discussed in detail in Section 4.0.

3.8 Weatherproof Enclosure

A weatherproof enclosure, manufactured by Safety Devices, Inc., Springfield, Virginia, was purchased to house some of the transmitting equipment in the field. Photographs of the enclosure are shown in Figures 20, 21 and 22. The inside dimensions of the enclosure are 24 1/2 inches wide by 30 3/4 inches high by 23 3/4 inches deep. The interior structure contains an equipment rack 23 1/2 inches high for holding standard 19-inch panel mount equipment. Two metal shelves, one sliding, are mounted on the rack. The enclosure is welded aluminum construction with a removable front door. The door when in place is held firmly against a rubber seal by eight strong spring latches. One padlock hasp is mounted on each side of the door. Small air vents on each side of the enclosure allow cooling air to circulate through the enclosure. Electric fans are mounted against each air vent inside the enclosure. Power wiring with a ground wire enters through a hole in the rear panel of the enclosure and connects to terminal posts in the interior for distribution. Internal wiring provides seven power outlets and a master switch.

The power splitter has been mounted inside the enclosure against the rear panel. Three feed-through connectors also mounted on the rear panel connect to the power splitter with short coaxial cables and provide the external connections to the antenna cables.

Figure 20. HAIR Weatherproof Equipment Enclosure, Door Locked.

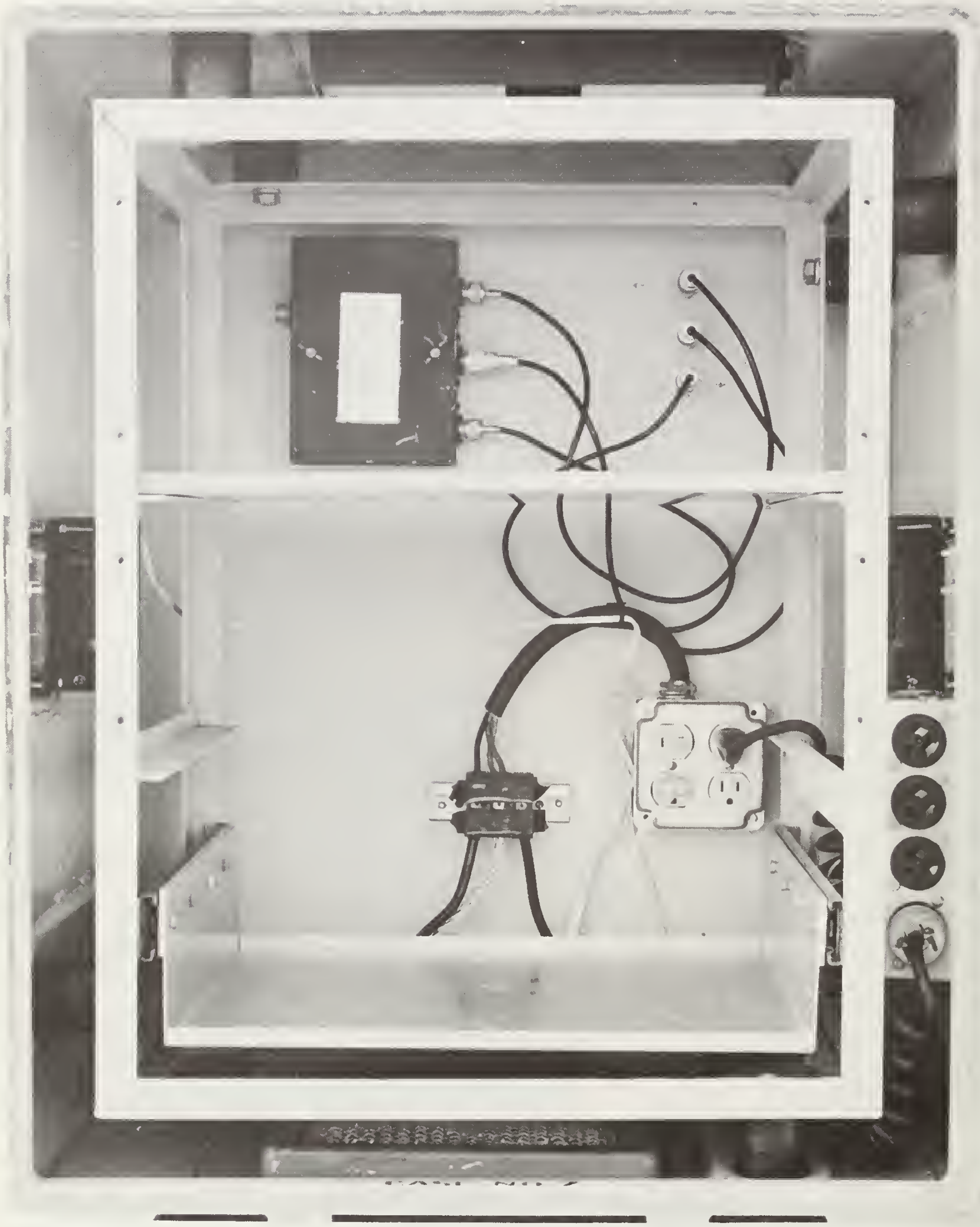


Figure 21. HAIR Weatherproof Equipment Enclosure, Interior View.

Figure 22. HAIR Weatherproof Equipment Enclosure, Rear View.

3.9 Estimated Large Unit Production Costs

During the procurement phase of this task large unit quotes were obtained on many of the system components ordered. The most significant impact in cost reduction was found to be through the use of Large Scale Integration (LSI). Informal discussions with Analog Devices, Inc. and other manufacturers revealed that although initial setup costs were high, when amoritized over a million or more units, this cost would only represent 7.5 cents per chip. Total chip costs would then vary from $2.50 to $15 depending on quantities specified. Atlantic Research Corporation's estimates for various quantities of the receivers, roadside and emergency vehicle components are shown in the following table. The 1 million quantity estimate is based on LSI of the logic board.

Application	200 units	10,000 units	1 million units
Automatic receiver	$ 85	$40	$15 (LSI)
Roadside system	$1,650		
Emergency vehicle system	$ 650		

4.0 SYSTEM TESTS AND EVALUATION

System tests and evaluation were performed at a site on the Dulles Access Road, Virginia. The site selected, shown in Figure 23, is located approximately 2 miles east of the Dulles Airport terminal along a straight section of the highway. Photographs of the test zone are presented in Figures 24 and 25. The test zone extends 4,000 feet along the south side of the highway. The Dulles Highway was mutually agreed to by the FHWA and was selected for its low density of traffic while still being representative of a limited access highway. The specific site location on the highway was selected because of its accessibility from Horse Pen Road and the nearby turnaround ramps at the Centerville Road exit and at the airport entrance. Also, a VEPCO power drop was available near this site. Other sections of this highway previously considered were dropped because they lacked one or more of these attributes.

Two principal tests were conducted at this site. One involved measuring the characteristics of various transmitting systems and the second was to validate the functional performance of the system, principally the automatic receivers.

Initially only one transmitting system – an array of three whip antennas fed by a single transmitter – was to be measured. Later during the contract performance period it was mutually decided to examine the performance of several cable antennas.

This section of the report describes the tests performed, instrumentation used and results of each test. The testing basically followed Section 4 of the Field Test Plan (Appendix C), Highway Advisory Radio, dated 15 April 1974, prepared by Atlantic Research Corporation and approved by the contract monitor.

4.1 Transmission Characteristics Test

4.1.1 Measurement Instrumentation

Although the test plan called for field strength measurements as discrete points along the eastbound lane through the test zone it was decided to use the instrumented Atlantic Research Corporation test van to record these data. The mobile test instrumentation is shown in Figure 26. The drive on the pen recorder was geared to the odometer cable and calibrated in feet. The limits of the pen displacement of the recorder were first determined by a dry run through the zone with the transmitters operating. Peak and null points along the zone were then revisited and the pen displacement calibrated to actual field strengths. Once calibrated this system provided a continuous recording of field strength for all transmission testing in mV/m versus position throughout the test zone and beyond. The test antenna was a short vertical whip on the vehicle.

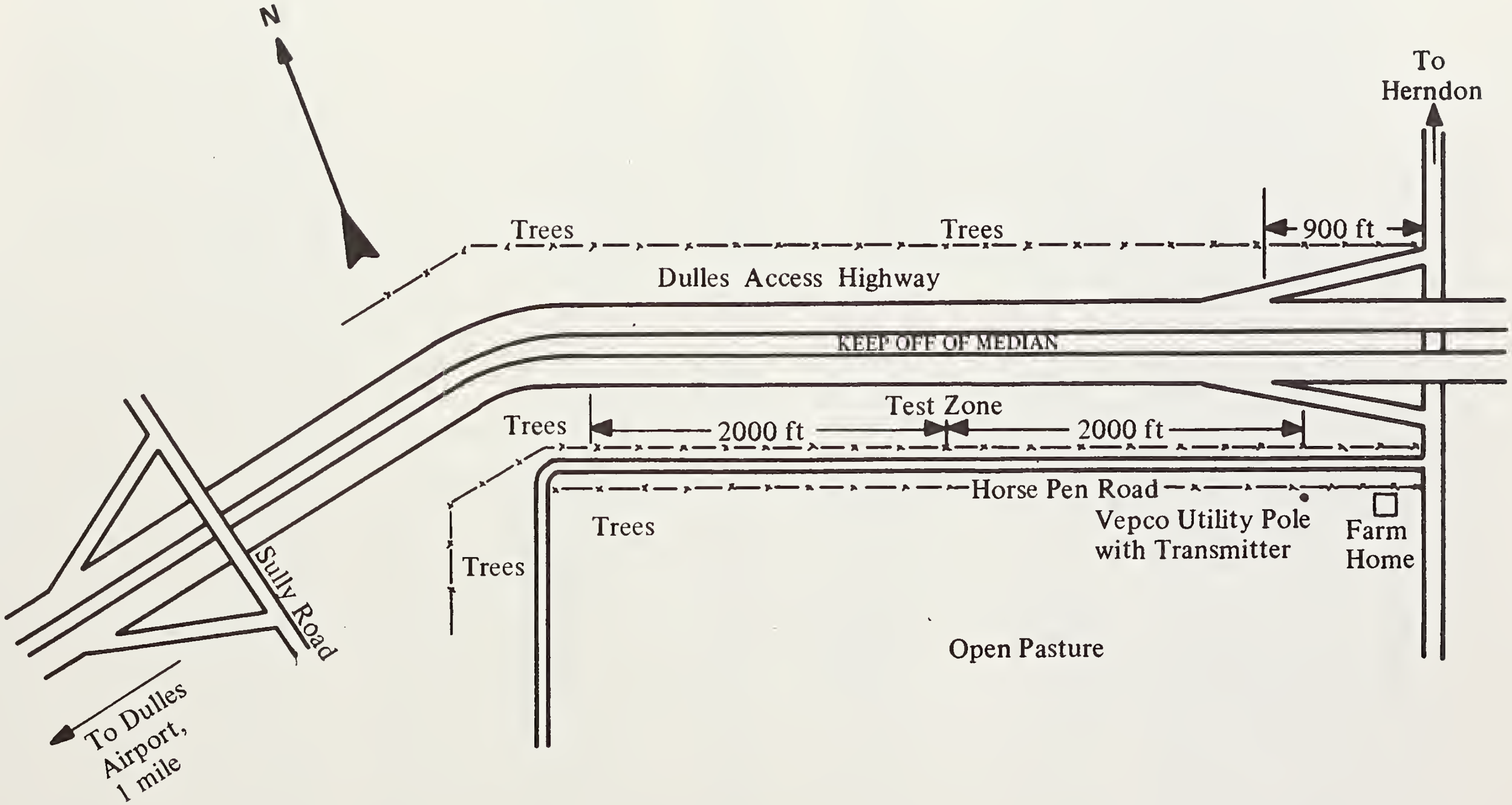


Figure 23. Map of Test Zone on Dulles Access Highway.

Figure 24. View of Test Zone Area, Looking East.

Figure 25. View of Test Zone Area, Looking West.

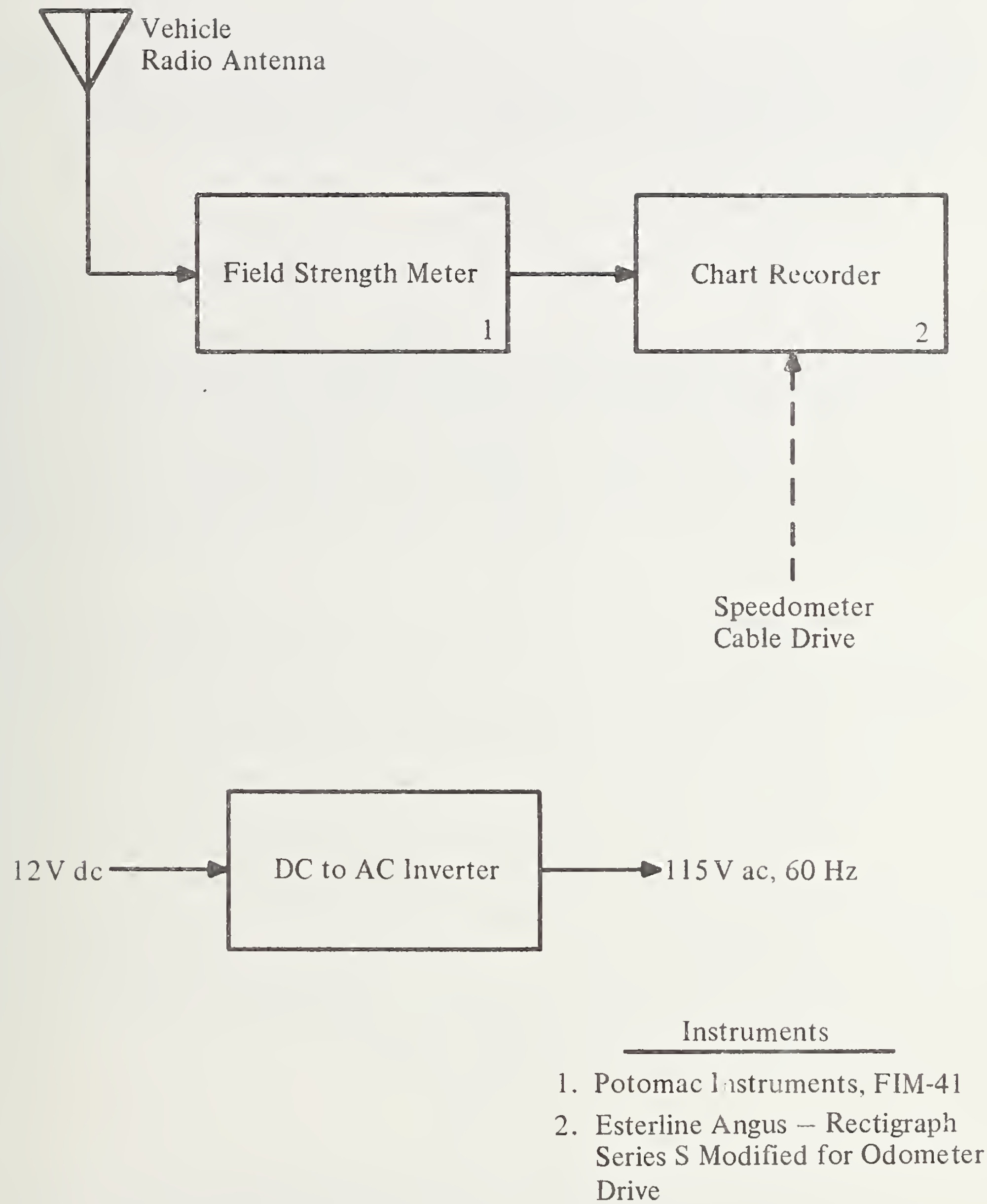


Figure 26. Block Diagram of Mobile Instrumentation for Recording Field Strength.

4.1.2 Whip Antennas

As already described in Section 3.7 two configurations of whip antennas were tested at each frequency – a three-antenna array, and a single antenna (the center whip in the array). In the three-antenna array, the antennas were placed along a line parallel to the highway with the center antenna located at the center of the test zone. The antennas were placed 50 to 100 feet from the nearest edge of the highway. This distance was selected to minimize the visibility of the antennas from passing motorists. Prior to taking field measurements the matching network at each antenna was adjusted for maximum radiated power and minimum VSWR in the transmitter cables. The transmitter power output was adjusted to a convenient level not exceeding 10 watts.

4.1.2.1 Whip Antenna Patterns at 530 kHz

The measured field strength patterns through the test zone at 530 kHz for both the single whip and the 3-whip array are shown in Figures 27 and 28, respectively. These curves correspond to a transmitter power output of 10 watts and a measurement distance of about 100 to 120 feet from the antenna baseline. The measured patterns can be seen to have similar shapes to the corresponding theoretical patterns presented in Section 3.7. Secondary radiation from currents induced in the shields of the connecting cables for the three-antenna array was discovered to exist and probably accounts for some filling in of field strength between antennas. As expected, the center antenna of the array produced the strongest peak signal due to minimum cable loss. The unequal peak magnitudes of the outer two antennas are attributable to different distances of these antennas from the highway.

Of principal interest is the absolute level of the minimum field strength occurring within the test zone. For the single antenna, the minimum field strengths occurred at the ends of the test zone and are seen in Figure 27 to be 1.5 mV/m at the west end and 1.8 mV/m at the east end. For the three-antenna array, minimum field strengths occured not only at the ends of the zone but also over relatively large sections of the zone between the antennas. The minimum levels are seen in Figure 28 to be between 0.54 mV/m and approximately 0.70 mV/m. The three-antenna array is thus seen to produce lower field strengths throughout most of the zone than the single antenna for the same total radiated power. Further comparison between the patterns reveals that 3 watts delivered to the single antenna provides essentially the same minimum field strength level (at the ends of the zone) as does 10 watts delivered to the three-antenna array. Consequently, the single whip antenna provided more efficient field strength coverage of the 4,000-foot test zone at 530 kHz than did the three-antenna array with 0.8 wavelength spacings.

4.1.2.2 Whip Antenna Patterns at 1606 kHz

The measured field strength patterns through the test zone at 1606 kHz for both the single whip and the 3-whip array are shown in Figures 29 and 30, respectively. These curves correspond to a transmitter power of 10 watts and a measurement distance of about 110 to 130 feet from the antenna baseline. The measured patterns compare favorably with the calculated patterns presented in Section 3.7. Secondary radiation from currents

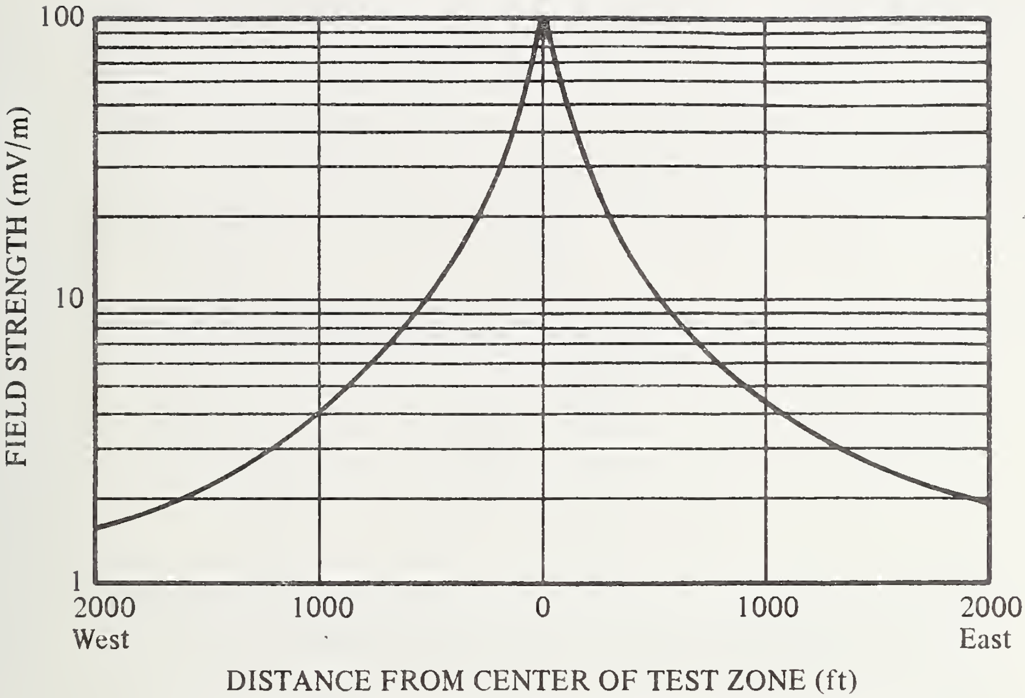


Figure 27. Measured Radiation Pattern Through Test Zone,
530 kHz, Single Whip Antenna, 10 watts.

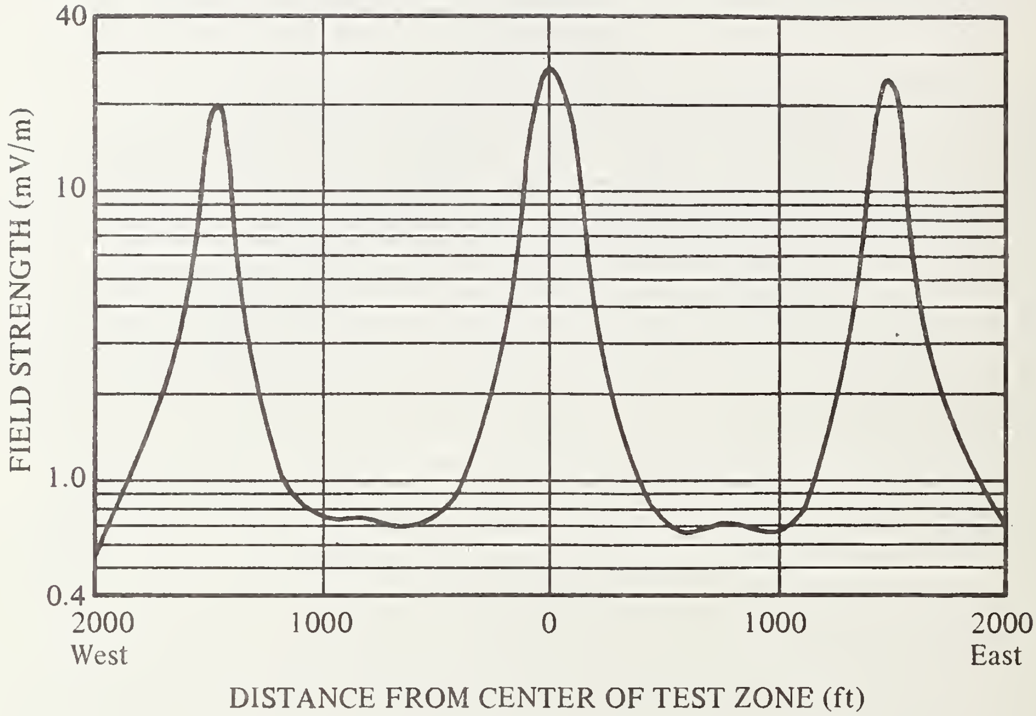


Figure 28. Measured Radiation Pattern Through Test Zone, 530 kHz, 3-whip Array, 10 watts.

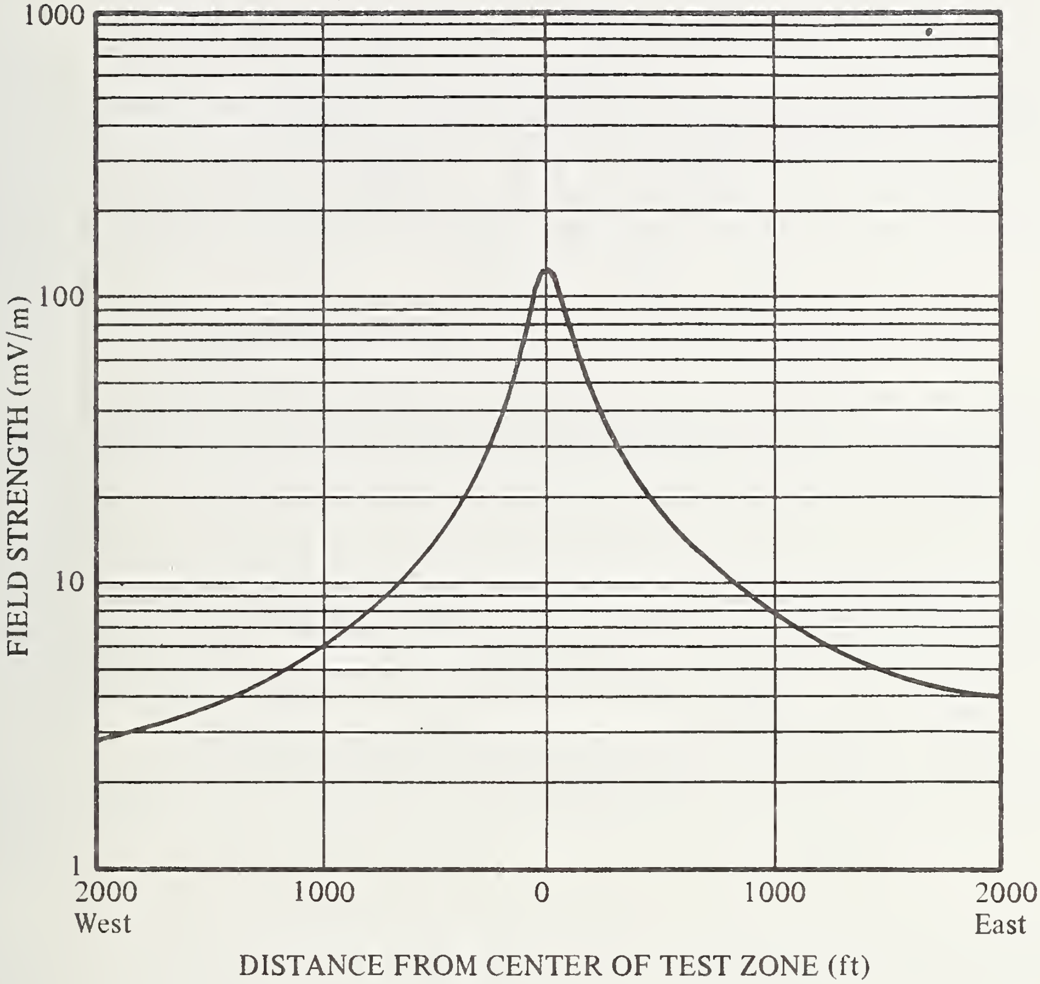


Figure 29. Measured Field Strength Pattern Through Test Zone, 1606 kHz, Single Antenna, 10 watts.

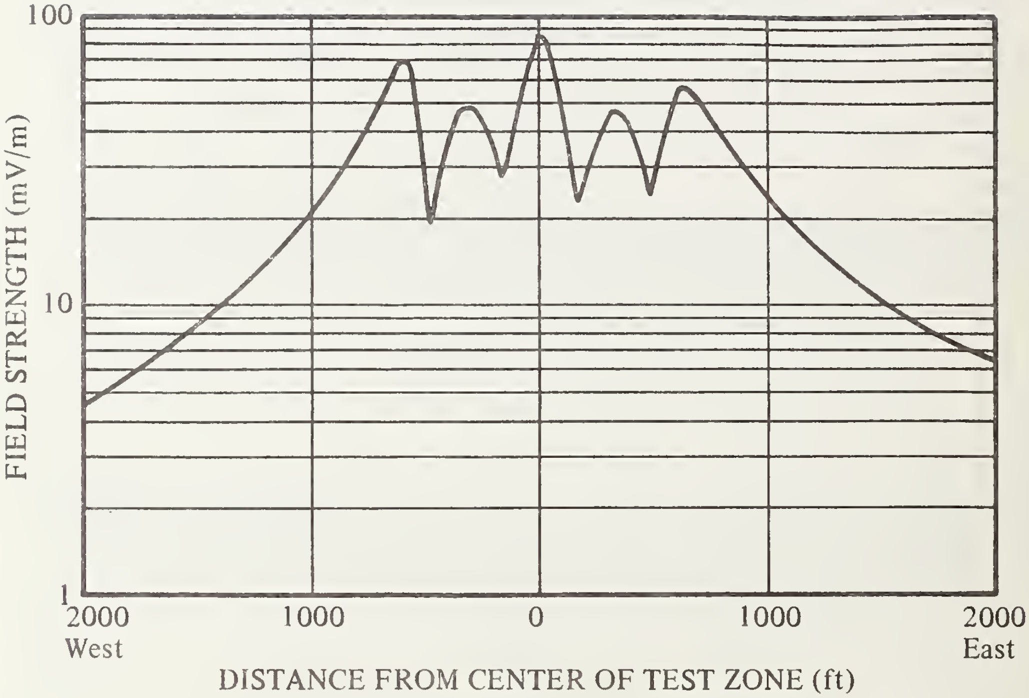


Figure 30. Measured Radiation Pattern Through Test Zone, 1606 kHz, 3-whip Array, 10 watts.

induced in the shields of the connecting cables for the three-antenna array perhaps account for some filling in of the nulls. The peak field strength of the center antenna is the largest in the array, as expected. The peak of the east antenna is lower than that of the west antenna due principally to unequal antenna distances from the highway. The uneven distribution of earth conductivity throughout the test zone also may account for other observed field strength anomalies.

The minimum absolute field strengths for the single antenna occurring at the ends of the zone are 2.8 mV/m at the west end and 3.5 mV/m at the east end. For the three-antenna array, the minimum field strengths clearly occur at the ends of the zone and are seen to be 4.5 mV/m at the west end and 6.0 mV/m at the east end. A relative comparison between the distributions of field strength for the two antenna systems indicates that the three-antenna array with one wavelength spacing, provides significantly better coverage throughout the 4,000-foot test zone at 1606 kHz, for the same total transmitter power.

4.1.3 Leaky Coaxial Antenna

One thousand feet of Andrews RADIAX type RX4-3A "leaky" coaxial cable antenna was tested at each test frequency at the Dulles test site. The cable, lying on the surface of the ground, was fed at one end with the transmitter set at 10 watts and terminated at the other end with 50 ohms. The vertically polarized radiation patterns measured along the highway 25 feet from the cable are presented in Figure 31. It can be seen that at 530 kHz the field strength varied between 0.5 and 1.0 mV/m over the entire length of the cable. The field strength at 1606 kHz rises to a peak value approximately 100 feet from each end of the cable. Along the major length of the cable the field strength varied erratically between the levels of 2.5 mV/m and 4.2 mV/m.

The radiation strength of the cable was measured for several locations of the cable. It was placed at the crest of a 10-foot embankment along the highway; however, this had the effect of only decreasing the field strength due to increased distance from the highway.

The electric field radiating from this cable appeared to be circularly polarized. Experiments with the cable by raising up a section 5 feet above the ground to increase the vertically polarized field resulted in significant increases in field strength (up to 20 dB) when received by a vertical whip antenna.

Although the RADIAX cable is intended to be buried in the earth for normal use, it is believed that the radiation tests performed at AM broadcast frequencies were valid with the cable above ground. Other users of buried cable antennas at similar broadcast frequencies have indicated that a 3-foot burial essentially increases the free space distance of the cable by 3 feet.

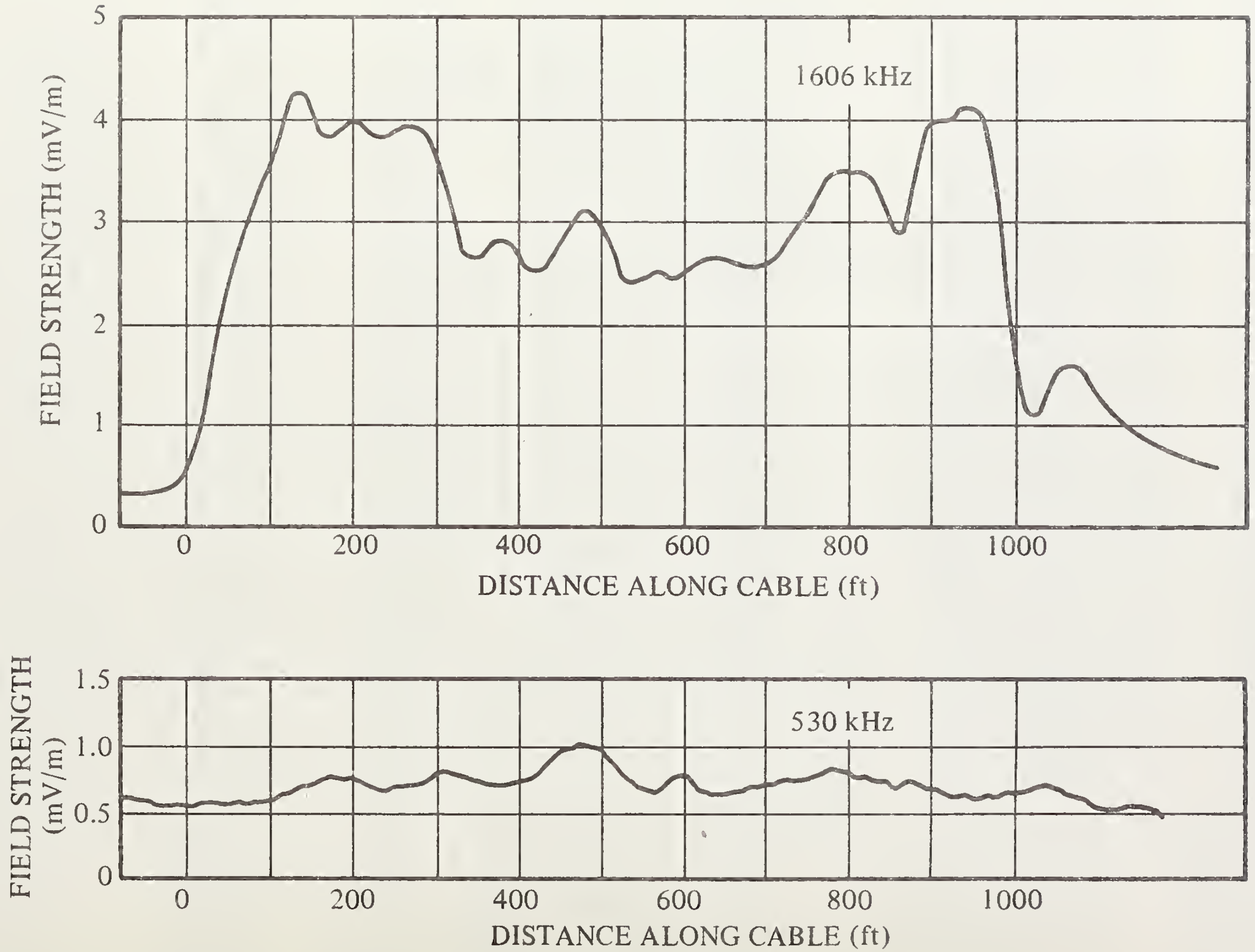


Figure 31. Measured Radiation Patterns of Andrews RADIAX Cable Antenna at 25 feet.

4.1.4 Induction Cable

One thousand feet of COM/SCOPE (Continental Cable Corporation) induction cable antenna was tested at both 530 kHz and 1606 kHz. The transmitter power was set to 10 watts and directly connected to one end of the cable. The other end of the cable was terminated in 50 ohms. With the cable lying on the surface of the ground near the highway pavement, recordings of the vertically polarized radiation pattern at 25 feet from the cable were made. These results are presented in Figure 32. It is seen that the field strength begins rising outside the ends of the cable and reaches a peak level within 100 feet inside the cable ends. At each test frequency the radiated field exhibits oscillatory variations with distance along the cable. At 530 kHz the average spacing between peaks is 165 feet, and at 1606 kHz the average spacing is 115 feet. The cause for these variations is not understood, for they cannot be standing waves in the ordinary sense at these frequencies.

The field strength at 530 kHz is seen to vary between 0.3 mV/m and 2.5 mV/m over the entire length of cable. At 1606 kHz the signal strength varies between 0.6 mV/m and 5.7 mV/m.

The patterns of measured field strength for the lossy cable antennas presented here were obtained using a whip antenna on a vehicle and correspond to the actual levels seen by ordinary automobile whip antennas. These values do not represent those received with a calibrated field strength meter using a loop antenna.

4.1.5 Conclusions of Antenna Characteristics Test

All antenna systems examined in this project appear to be potentially usable for providing limited radiation coverage for a HAIR system. The vertical whip antennas can provide adequate field strengths for reliable operation of the automatic receivers using 10 watts or less of transmitter power. Also, the lossy cable antennas are definitely compatible with the HAIR system. Further studies, however, should be made with the two types of antennas before their radiation characteristics can be accurately specified.

Additional development of the matching networks for the whip antennas is required to establish the design of efficient networks that will be stable over a wide range of ambient temperatures. The matching networks developed in this project consisted of ferrite pot cores wound with Litz wire. The high capacitive reactance of the antennas required series matching coils of relatively high inductance, particularly at 530 kHz. As a result the coils became warm or hot when delivering more than 1 watt of RF power to the antennas. As already mentioned, the matching network for the single whip antenna was unable to pass more than a few watts of RF power before overheating. This heating represents a loss of transmitter power due not only to the heat radiated but also to the corresponding detuning of the series inductance because of the high temperature. The overall efficiency of the whip antenna depends largely on the efficiency of its matching coil or network. Also, the radiation performance of a whip antenna over earth at broadcast frequencies depends on ground losses which can vary with location and possibly weather. Further studies should be made to determine the relationship between antenna impedance and type of soil and to develop the most effective grounding system suitable with the roadside HAIR installations.

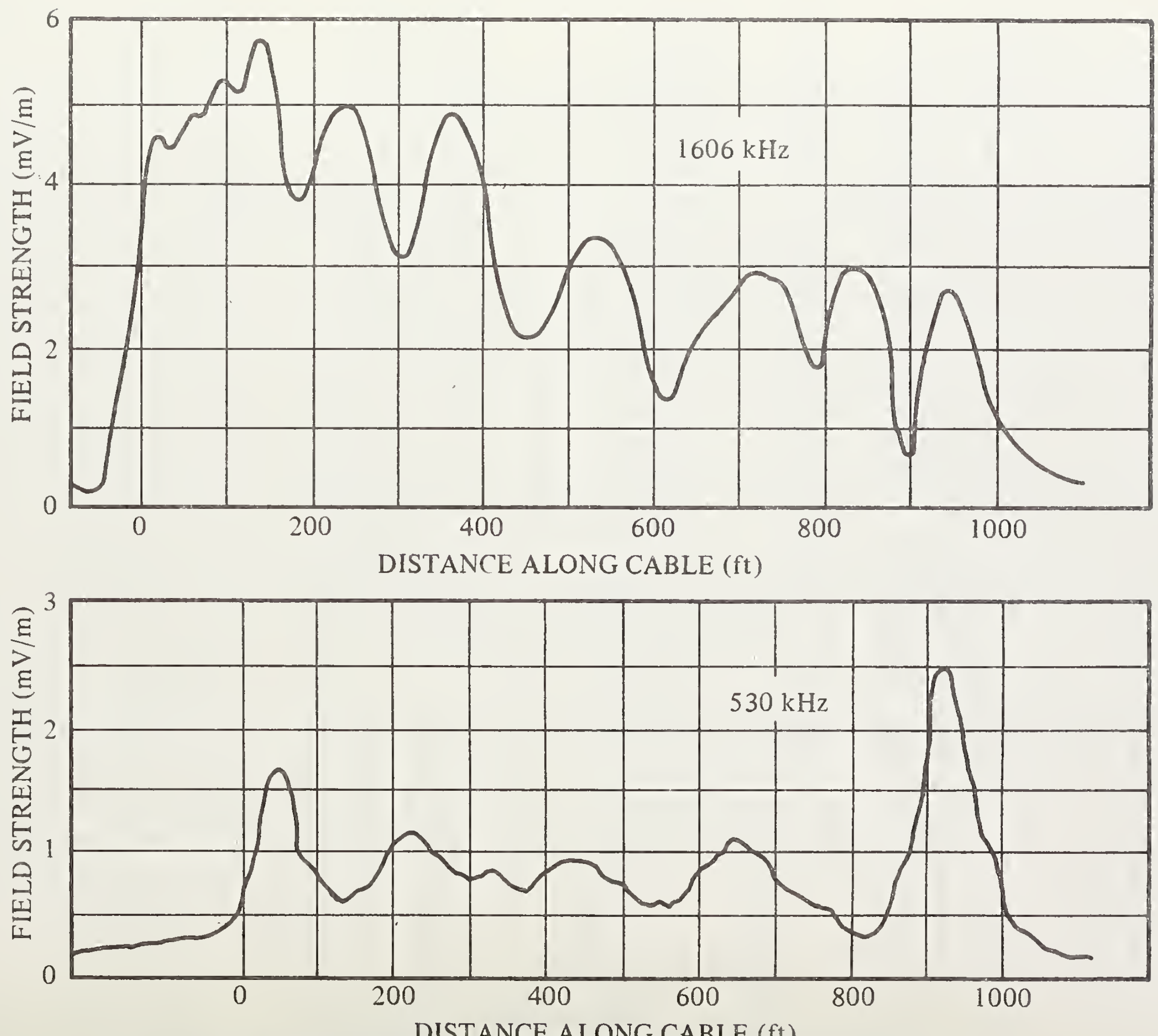


Figure 32. Measured Radiation Pattern of COM/SCOPE Induction Cable Antenna at 25 feet.

Further study, both empirical and theoretical, should be made to develop a better understanding of cable antennas. More information is needed to characterize the magnitude of the vertically-polarized electric field radiated from a cable antenna for a given amount of input power. Also, the system tests involved only 1,000-foot lengths of two types of lossy cable antennas. The effectiveness of this kind of radiator over a 4,000-foot coverage zone for the HAIR system with 10 watts of transmitter power is uncertain.

The results of the tests with whip antennas have shown that there is no significant advantage in using an array of radiators. At both test frequencies of 530 kHz and 1606 kHz a single whip antenna provided adequate field strength coverage of the 4,000-foot test zone with less than 10 watts. The use of only one whip antenna greatly simplifies the installation of the roadside transmitter and provides a practical means for achieving the desired zone coverage with a relatively small amount of antenna space required. The cable antenna, on the other hand, must extend the full length of the coverage zone as the effective radiation zone of the cable antenna is less than 100 feet from the cable for 10 watts of power. There are, however, several advantages and disadvantages with each type of radiator, and in general one type cannot be recommended over the other for all installations. Some of the primary advantages and disadvantages with each type of antenna are as follows:

Whip Antenna

a. It is physically small and can be installed in a relatively small space.

b. It is relatively easy to install. It can be installed in a short time in various environments over earth or pavement, on a building or tower, etc.

c. The whip antenna can be portable or can be easily relocated to other sites.

d. The whip antenna will usually be visible but can be camouflaged to some degree.

e. It can be placed several hundred feet from the highway.

f. It is subject to damage by weather, accident or vandalism.

g. The whip antenna requires a matching network (or series inductance) that is efficient, stable, reliable, and easily tunable.

h. The whip antenna provides a circular zone of coverage that may interfere with other coverage zones on adjacent highways.

i. The coverage zone extends well beyond the limits of the intended zone and thus may overlap with other coverage zones on the same highway.

j. It will usually be less costly to purchase and install than a cable antenna.

Lossy Cable Antenna

a. It must physically extend the full length of the coverage zone.

b. It may be emplaced above or below ground.

c. It can provide continuous coverage through tunnels, in buildings, under overpasses, etc.

d. It is more costly to purchase and install, especially if buried.

e. It is not easily relocated, especially if buried.

f. It is not easily installed in some areas already built up with concrete pavement and highway structures, such as through a highway interchange or intersection.

g. It can be made invisible, especially if buried.

h. The cable antenna is easily connected electrically and requires no matching network or tuning adjustment.

i. The radiation zone is confined to within 100 feet or less from the cable, and thus minimizes interference with nearby coverage zones.

j. It must be placed close to the highway.

k. If installed below ground it is not subject to damage by weather or vandalism.

1. The radiation is stable with temperature and weather and is relatively unaffected by the type of soil if buried.

The choice of the type of antenna depends on a consideration of such factors as:

a. Permanency of installation.

b. Practicality of installation along existing highway.

c. Limitations on size of radiation zone of coverage.

d. Costs of purchase and installation.

e. Protection and concealment.

f. Engineering considerations of radiation versus power.

In addition, the field tests have indicated that the whip antennas may require considerably less than 10 watts of transmitter power to radiate adequately throughout the coverage zone, whereas the cable antennas will require perhaps 10 watts or more to ensure adequate field strength to at least 50 feet from the cable.

The application of either the short, vertical whip antenna or the lossy cable antenna is also subject to the findings of more extensive studies of each type. The limited testing of each type performed in this project have indicated that there are definite advantages apparent with each type of radiator, as both are suitable for use in the HAIR system.

4.2 System Operational Performance Test

The second major test effort at the Dulles site was a thorough testing and evaluation of the operational performance of the HAIR receivers inside an automobile while driven through the test zone. The overall objective of these tests was to examine the performance of the integrated HAIR system to reliably communicate pre-recorded voice messages with appropriate tone coding to the motorists having automatic HAIR receivers. All components of the HAIR system were placed into operation in these tests and thereby became interdependent elements of the system. Consequently, these system tests afforded an opportunity to observe the compatibility of each element within the entire system. Limitations of some of the components that did not appear during laboratory tests became evident during the system tests. Some of the specific objectives of these tests were: (a) to observe that the roadside transmitting system could transmit suitable signals for operating the HAIR receivers, (b) that all automatic functions of the HAIR receivers could operate correctly, and (c) that each type of antenna system could provide sufficient field strength throughout the intended radiation zone to result in reliable receiver operation at any location in the zone.

4.2.1 Test Setup and Procedure

The encoder, tape recorder, and transmitter were installed in the equipment enclosure at the center of the test zone. Test messages containing a series of automatic tone coded commands with brief voice identifications were carefully timed and recorded onto a 40-second tape loop. The recorded message sequence provided a convenient method of testing all receiver functions. Following the power adjustment of the transmitting carrier signal, the taped message was played back into the transmitter, and modulation adjustments of the signal were made with the aid of a monitor oscilloscope. The appropriate antenna system at the desired channel frequency was also established. (Setup and Calibration Procedures are covered in Appendix E.)

The HAIR receivers were installed in a passenger vehicle as shown in Figure 33. The Adaptor and Integrated receivers and a commercial AM radio for use with the Adaptor were all mounted to a common support which was bolted under the dashboard. Two separate automotive whip antennas on the vehicle were connected to the two HAIR receivers. DC power for the entire assembly was furnished through a cord that plugged into the cigarette lighter. Appropriate connections were made between the Adaptor unit and the commercial radio.

The Portable receiver, not shown in Figure 33, was mounted vertically on top of the dashboard for testing. In this position the figure-8 pattern of the ferrite loopstick antennas was oriented with the peaks in the direction of the highway and the nulls to the right and left sides of the vehicle. DC power was obtained through a cord that plugged into the cigarette lighter.

Special markers were set up at the side of the highway to signify the boundaries of the 4,000-foot test zone. Vehicle positions within the zone were determined either from odometer readings or from the relative positions with respect to the transmitting antenna locations.

The tests were performed by observing the response from each of the HAIR receivers while driving eastbound through the test zone in either the inner or outer lane of the Dulles Highway. The principal concern of the operational tests was the ability of the receivers to perform their automatic and manual functions. In particular, the following receiver functions and responses were noted:

a. Manual channel selection.

b. Automatic channel selection.

c. Automatic reception of the traffic message. This includes the ability to capture the message from its beginning and to maintain reception until the end of the message.

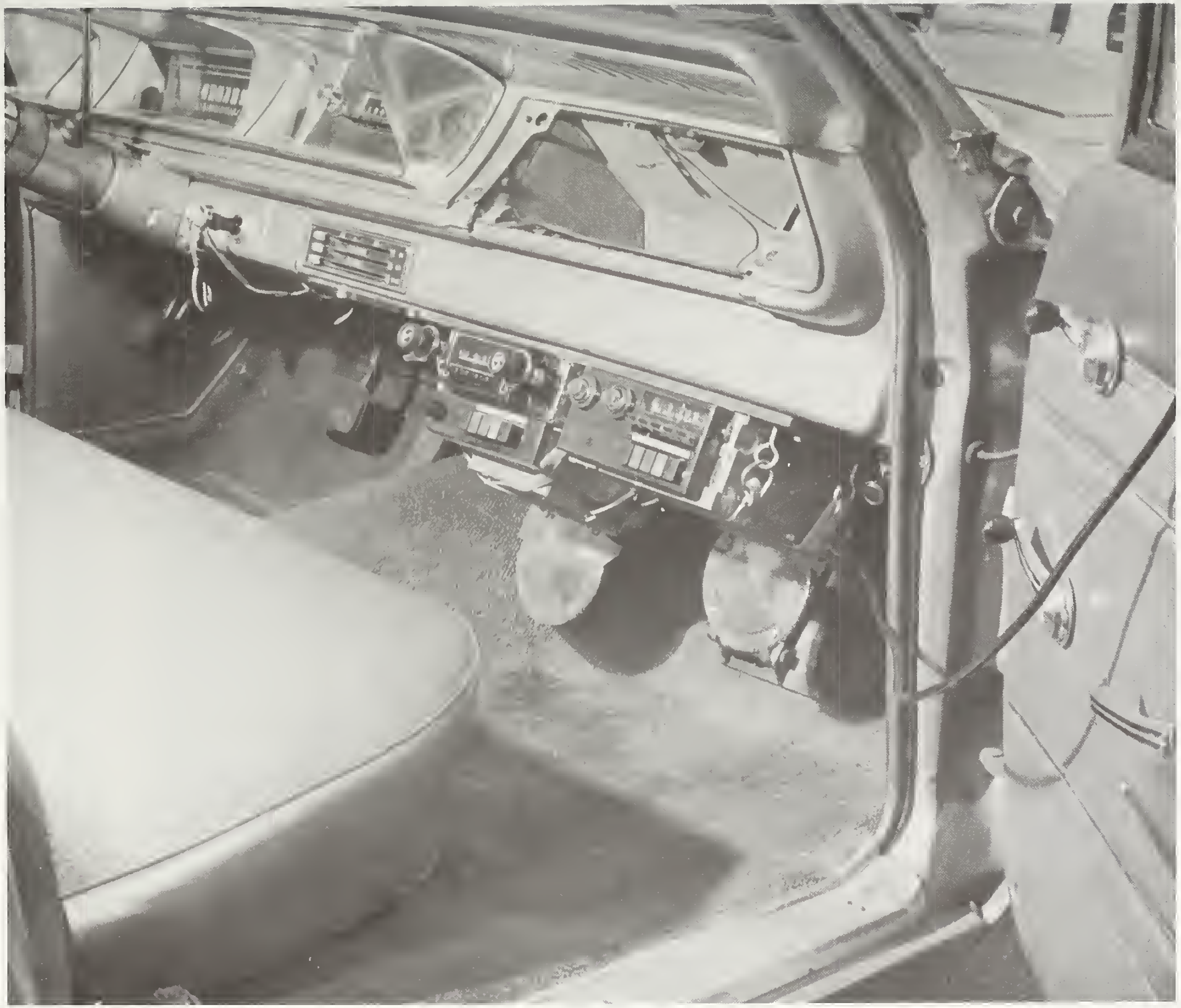


Figure 33. Test Installation of Adaptor and Integrated Automatic Receivers in Vehicle.

d. Pre-emption of a message by the manual selection of a message level of higher priority.

e. Reception of the emergency warning message on all message priority levels. This includes the flashing of the emergency light.

f. Automatic lockout after receiving one trip advisory or trip information message in a series (unless the subaudible tone is interrupted).

g. Automatic muting of automobile receiver during message reception and release at end of message.

h. Audio fidelity of voice message.

i. The ability to perform the above during low-speed and high-speed driving.

When difficulties in message reception were experienced every possible effort was made in the field to determine the cause and to make adjustments throughout the sytem that would optimize the operational performance of the receivers for the given antenna system and channel frequency.

The testing procedure was repeated for the one- and three-antenna systems at both frequencies, and for the cable antennas at both frequencies. Also, the tests were made in each eastbound traffic lane of the highway.

4.2.2 Test Results and Evaluation

Considerable difficulty was experienced with the performance of message reception during initial tests of the system. The receivers did not always operate consistently. The sensitivity level at times varied significantly from day to day with the Adaptor and Integrated receivers. Often the receivers would not capture a message with a field strength that was known to be adequate. The major causes of these difficulties were eventually traced to two important factors related to the receiver design.

First, it will be recalled (Section 3.5.2) that the subaudible tone (SAT) must be continuously present in the receiver in order for the decoding circuitry to function. Momentary interruption of the tone at any time during a message terminates all automatic functions of the receiver, and the remainder of the message is lost until the starting code of the next message is received. More specifically, the output voltage level of the SAT tone decoder must remain at ground potential to effect proper operation of the receiver and logic decoder. This output voltage level rises to +12 volts dc whenever the SAT tone decoder loses lock on the SAT in the detected signal. This loss of lock can occur for several reasons in

addition to the lack of presence of the SAT. Interfering noise or other low frequency tone signals, if sufficiently strong, can disrupt the tone decoder lock even while the SAT is present. In particular, it was discovered that waveform transients at the beginning and end of each logic tone burst in the detected signal could disrupt the locking of the SAT tone decoder depending upon the relative amplitudes of the two signals. After considerable experimenting with each receiver using various signal ratios established at the encoder, it was discovered that the ratio of the peak amplitudes of the 82.5 Hz SAT or the audio logic tones must be set within the range of 50 to 100 percent in order for the receivers to operate properly. Excessively high ratios of relative SAT amplitude can also lock up the logic decoder resulting in improper functioning of the receiver. Consequently, it was found that the relative amplitude of the SAT as established at the transmitter must be held between specific upper and lower limits to effect proper operation at the automatic HAIR receivers. This ratio is usually set at about 75 percent.

Some of the difficulty experienced during initial system tests was the result of insufficient relative SAT amplitude. Although sufficient absolute SAT amplitude was present in the detected signal to activate the SAT tone decoder, arrival of the tone bursts caused momentary disruption of the SAT tone decoder with each burst. As a result, the receiver was unable to capture the messages. Some of the inconsistent behavior of receiver operation was due to inadvertent adjustments of the relative SAT amplitude at the transmitter. Also, it was discovered that when the SAT is included in a recorded message on the tape recorder with a given SAT/audio tone ratio, upon playback this ratio is reduced 50 percent due to the audio frequency response of the recorder. Consequently, twice the desired SAT ratio must be used during recording of the SAT with the complete HAIR signal.

The second problem with the HAIR receivers discovered during the initial system tests involved the effectiveness of the antenna tuning traps in the adaptor and integrated radios. These traps did not always provide adequate isolation between the HAIR receiver and the associated automotive radio at the channel frequencies. It was found during system tests, for example, that the sensitivity of the Adaptor radio improved considerably when the auxiliary antenna cable to the auto radio was disconnected. It was discovered that the front-end tuning circuits of the auto radio caused some degree of loading to the traps. As a result, the tuning at the traps depends on the specific auto radio connected, and further, tuning the dial on the auto radio can detune the traps. The tuning procedure which seemed to provide optimum isolation between the two receivers at all tuning positions of the auto radio was to tune the traps for maximum isolation with the auto radio dial set mid-band, near 1,000 kHz.

After this isolation problem was realized a separate automotive AM receiver was purchased for use in conjunction with the adaptor to ensure that the traps would provide stable isolation at all times.

With the above problems resolved, operational tests of the receivers proceeded and indicated that all required automatic and manual decoding functions of each receiver could be made to perform provided the field strength was adequately strong. That is, the successful operation of the HAIR system depended almost entirely on the absolute field strength available throughout all points of the test zone. It became evident that there exists a minimum threshold of field strength below which the SAT does not have sufficient amplitude in the detected signal to activate its tone decoder. Due to the requirement that the subaudible tone must be continuously received and processed, the HAIR receiver failed to capture or operate reliably when the vehicle was located in regions where the field strength was at or below the particular threshold level for the receiver. Measurements of these threshold field strengths were made for each receiver at each channel frequency. Repeated measurements of these values on different days showed some variation; however, the values which are tabulated below, provide an indication of the minimum field strengths required.

Table 3. Field Strength Capture Sensitivities of HAIR Receivers.

Unit	530 kHz (mV/m)	1606 kHz (mV/m)
Adaptor	0.09	0.34
Integrated	0.09	0.33
Portable	1.2	0.84

The values in the above table were measured after each receiver had been aligned and adjusted for maximum sensitivity with proper bandwidth. In field strengths at or very near the threshold levels the performance of the receivers may be unreliable and may fail altogether. The minimum field strength within a message zone should be at least 6 dB above the values shown in Table 3 to provide satisfactory operation of the HAIR system.

Generally, the performance of the HAIR receivers at 530 kHz was satisfactory, while the performance at 1606 kHz was excellent. Of the three receivers, the Integrated unit performed the best. The difficulty experienced at 530 kHz was due largely to insufficient field strength. The receivers would capture the coded signals, and although all automatic functions appeared to operate the voice messages were often unintelligible due to low signal-to-noise ratio. The audio message was least intelligible at 530 kHz when the vehicle was located either at the ends of the zone or between antennas. The audio intelligibility depends largely on the ambient noise level and the presence of ignition noise. Consequently, during the 530 kHz tests the minimum field strengths that provided intelligible reception depended upon vehicle speed, road noise, windows open or closed, engine on or off, etc. Estimates of this minimum field strength for normal highway speeds with the windows closed are approximately 1 mV/m for the Adaptor and Integrated receivers and 4 mV/m for the Portable. The audio power of the Portable receiver is insufficient for use during highway driving at 55 mph. For all three receivers the subaudible tone was audibly noticeable and caused slight degradation to the audio fidelity.

The receivers at 1606 kHz operated reliably throughout the zone using either the single-whip or the three-whip array. All automatic receiver functions performed satisfactorily; however, the voice quality of the Adaptor unit was fair due to presence of ignition noise generated apparently by the test vehicle. The audio power of the Portable receiver was inadequate during high-speed driving. As with 530 kHz, the subaudible tone could be heard and degraded the audio fidelity.

System tests using the two types of cable antennas showed, in general, that at 530 kHz the receivers performed fair to good with each cable, although the response with the COM/SCOPE cable was slightly better than with the Andrews RADIAX. The best performance, of course, was observed with the vehicle in the outer lane which was closer to the cable.

At 1606 kHz the receivers performed marginally well with each cable, but, as with 530 kHz, better results occurred with the COM/SCOPE induction cable than with the Andrews RADIAX. The above response for the Andrews cable was observed in the outside (near) lane only; the receivers failed to operate in the inside (far) lane for this cable. However, the observed responses with the COM/SCOPE cable were made in both eastbound lanes.

As mentioned earlier, the automatic HAIR receivers could be made to function satisfactorily with each antenna system. Since it was evident that the limiting factor for success was the magnitude of field strength, efforts were made throughout the system to maximize the radiated signal. More specifically, however, the amplitude of the subaudible tone after detection in the receiver must be maximized, and this can be achieved with maximization of each of the following:

a. Transmitter power

b. Percent modulation of SAT

c. Antenna tuning

d. Receiver sensitivity.

The transmitter carrier power was usually set to about 8 to 10 watts; however, for the single-whip antenna at 530 kHz, the power was set at 4 watts for the tests to avoid overvoltage and overheating problems in the matching network. The percent modulation was based on the amplitude of the audio tone bursts and was set initially to 30 percent. Later, this was increased to 50 percent in order to increase the SAT proportionally. The antenna tuning was checked occasionally and was found to remain stable. Each of the receivers were returned to the laboratory occasionally for checks of alignment and sensitivity.

5.0 AUTOMOBILE RADIO SURVEY

5.1 Introduction

This study and development program for a Highway Advisory Information Radio system has involved the use of radio frequency channels associated with the standard AM broadcast band (540 to 1600 kHz). System requirements dictate that two independent frequency channels be assigned for use by the HAIR system. Since the HAIR system can be expected to become a nationwide service, it is important that the two frequencies dedicated to HAIR service be selected on the basis of several practical considerations which are vital to the effectiveness of the system. The frequencies should provide relatively interference-free reception. A HAIR channel should especially not be assigned the same frequency as a local broadcast station. In view of the relative importance of the HAIR system concept and the crowded spectrum situation existing throughout the standard broadcast band, the Federal Communications Commission has given experimental license to the use of frequency channels slightly outside the band for the HAIR system. Following this decision, the principal problem was that of determining two optimum frequencies. This frequency selection must also consider the requirement that the HAIR system be designed to permit the motorist to receive the HAIR messages on a standard automobile radio. Therefore, the channel frequencies must be sufficiently near the broadcast band to result in their being received by a vast majority of commercial AM automobile receivers, while, at the same time, they should be sufficiently far removed from the band to avoid interference and to not place overly stringent selectivity requirements on the design of the special pretuned HAIR receivers.

Consequently, the purpose of Task 1 of this study program was to determine the optimum frequencies outside the AM broadcast band that would: (1) permit an automatic receiver design with reasonable selectivity at minimal cost, and (2) be usable by the motoring public with only an AM automobile receiver. The major effort in accomplishing Task 1 was the gathering of data pertaining to the tuning range, selectivity, and sensitivities of commercial AM automobile radios. These data were obtained in several ways: a literature search, inquiries with U.S. automobile radio manufacturers, and survey measurements by Atlantic Research of approximately 400 automobile radios.

This section presents a description of the various surveys taken, the data gathered, and the results of statistical analyses of these data.

It may be noted that initial consideration was given to using 530 kHz and 1610 kHz for the HAIR frequencies. However, licensing by the FCC was for 530 kHz and 1606 kHz since 1610 kHz had already been assigned for another use.

5.2 Literature Search

A literature search was performed to identify automobile radio tuning capability information. Bibliography requests to the IEEE Information Service and to the National Technical Information Service (NTIS) did not provide any sources of data.

As a matter of interest, yearly figures for total U.S. market of automobile radios were obtained from Electrical Industries Association (EIA), and the yearly figures for total U.S. production of automobiles were provided by the Automobile Manufacturers Association. These figures (not shown here) indicate, for example, that between 7 and 8 million automobiles were produced yearly from 1968 to 1970 while the total number of AM automobile radios sold in the U.S. was between 8 and 11 million for those years. The figures for automobile radios include after-sales market, trucks, tractors, boats, replacements and other uses of 12-volt dc radios. The Automobile Manufacturers Association estimated that 117.6 million passenger cars were registered in the U.S. in 1972. An estimated 90 to 95 percent of all new cars are sold with radios installed.

5.2.1 O.E.M. Specifications

In order to obtain tuning characteristics of present automobile radios, offices of General Motors Corp., Ford Motor Co., Chrysler Corp., Motorola Communications and Electronics were contacted.

The Philco-Ford Automotive Entertainment Section in Lansdale, Pennsylvania, provided technical information on Ford Motor Company radios. The specified bandwidth covers 530 kHz (+9, -10 kHz) to 1610 kHz (+10, -5 kHz). Production units center about 530 kHz to 1608/1610 kHz.

The Motorola Automobile Radio Engineering Section at Aurora, Illinois, indicated that the current tuner specification is approximately 525/530 kHz to 1610 kHz.

Discussions with engineering personnel at Delco Electronics indicated some uncertainty about the exact specifications. In general, the tuning stop for their units is set at about 1615 kHz. The mechanical design of various tuner mechanisms results in differing band spreads for different Delco models. Basically, a singel RF design results in about six different over-travel specifications.

The radio manufacturers indicated that there have been no significant changes in receiver characteristics since going to solid-state design. Most manufacturers are now meeting selectivity requirements of 7 to 10 kHz and signal sensitivity of 5 to 10 microvolt for 1 watt audio output.

5.2.2 Documented Tuning Range Tests

Three documents were identified and obtained concerning past efforts to measure automobile radio tuning characteristics above 1600 kHz and below 540 kHz.

The FCC reports in Memorandum dated December 27, 1971, that seventeen Commission employees' automobile radios were checked for ability to tune above 1600 kHz. Of the seventeen tested, it was found that:

a. 76 percent would tune to 1610 kHz

b. 53 percent would tune to 1615 kHz

c. 41 percent would tune to 1620 kHz.

The FCC also reports in Memorandum dated August 18, 1972 that another survey was conducted on 58 automobile radios to check their tuning ability below 540 kHz. Of the 58 tested, it was found that:

a. 90 percent would tune to 535 kHz

b. 69 percent would tune to 530 kHz

c. 55 percent would tune to 525 kHz

d. 29 percent would tune to 520 kHz.

RTV Management, Inc. in Exhibit H of their Interim Report to the FCC, dated October 1972, reported on survey measurements of 100 cars tested at 530 kHz and 55 cars tested at 1614 kHz. The results of this survey indicated that 94 percent could tune to 530 kHz, and 72 percent could tune to 1614 kHz.

The above reports are the only known documented tests of this kind. The samples are small and there is significant disagreement in their respective results. The reason for the discrepancies is not known; however, it is felt that the relative sample size and the type sample in each case may have biased the results. The RTV group used relatively new (1972 rental cars) while the FCC sample consisted mainly of employees cars. It became quite clear that the Atlantic Research tests must use a much larger sample.

The FCC tuning data and the significance of the percent figures given above will be discussed in subsequent subsections.

5.2.3 AM Radio Survey Measurements

During the period of this contract, Atlantic Research undertook several measurement surveys of actual AM (and AM/FM) automobile radios in order to provide an adequate data base for this study. Survey I, performed in May/June 1973, obtained upper and lower frequency tuning limits of 345 automobile radios. In December 1973, additional measurements were made on nine AM radios to provide data relating to out-of-band tuning. Survey II, performed in July 1974, obtained sensitivity data along with additional tuning range data from 54 automobiles. Each of these surveys and their results are discussed in detail below.

Survey I was performed at two northern Virginia locations: in the Atlantic Research employee parking lot and the parking lot of the Landmark Shopping Center nearby. Drivers, when entering or leaving the parking lots, were asked to stop for about one minute and cooperate with the test procedure. The driver was requested to manually tune his AM radio to one extreme end of the tuning range. A tunable RF generator connected to a small transmitting antenna and modulated with a 1000 Hz audio tone was adjusted until the maximum response of the tone could be heard from the radio speaker. The frequency of the carrier was then measured by a frequency counter. The driver was then requested to tune his radio to the other extreme end of the band, and the measurement was repeated. Both of these frequencies were recorded along with the make and year of the car.

The resulting data plotted in ascending order of frequencies is presented in Figure 34 for the lowest tunable frequencies, and in Figure 35 for the highest tunable frequencies. These curves show, for example, that approximately 72 percent of the automobile radios could tune to 530 kHz and 66 percent could tune to 1606 kHz. The data also revealed (not shown) that 49 percent of the radios could tune to both frequencies while 10 percent could tune to neither.

The frequencies measured ranged from 493 kHz to 655 kHz, at the low end and from 1497 kHz to 1721 kHz at the high end.

With regard to the make of car, the Survey I data indicated that the radios in General Motors automobiles tended to show the highest percentages for both the lower and upper tuning limit frequencies. Radios in the Chrysler Corporation automobiles tended to show the lowest percentages and the radios in Ford Motor Company automobiles were in between GM and Chrysler.

It should be remarked that the percentage figures given above for the Survey I data were determined from a count of the number of radios that could be tuned exactly to a specified frequency. For example, a radio having a tuning limit of 531 kHz or higher was not considered capable of tuning to 530 kHz. Similarly, a radio with a tuning limit of 1605 kHz or less was considered not to be tunable to 1606 kHz. The treatment of these frequency data in this discrete manner is not desirable as the results can easily lead to misinterpretation. Consideration will be given to the significance of the Survey I frequency data.

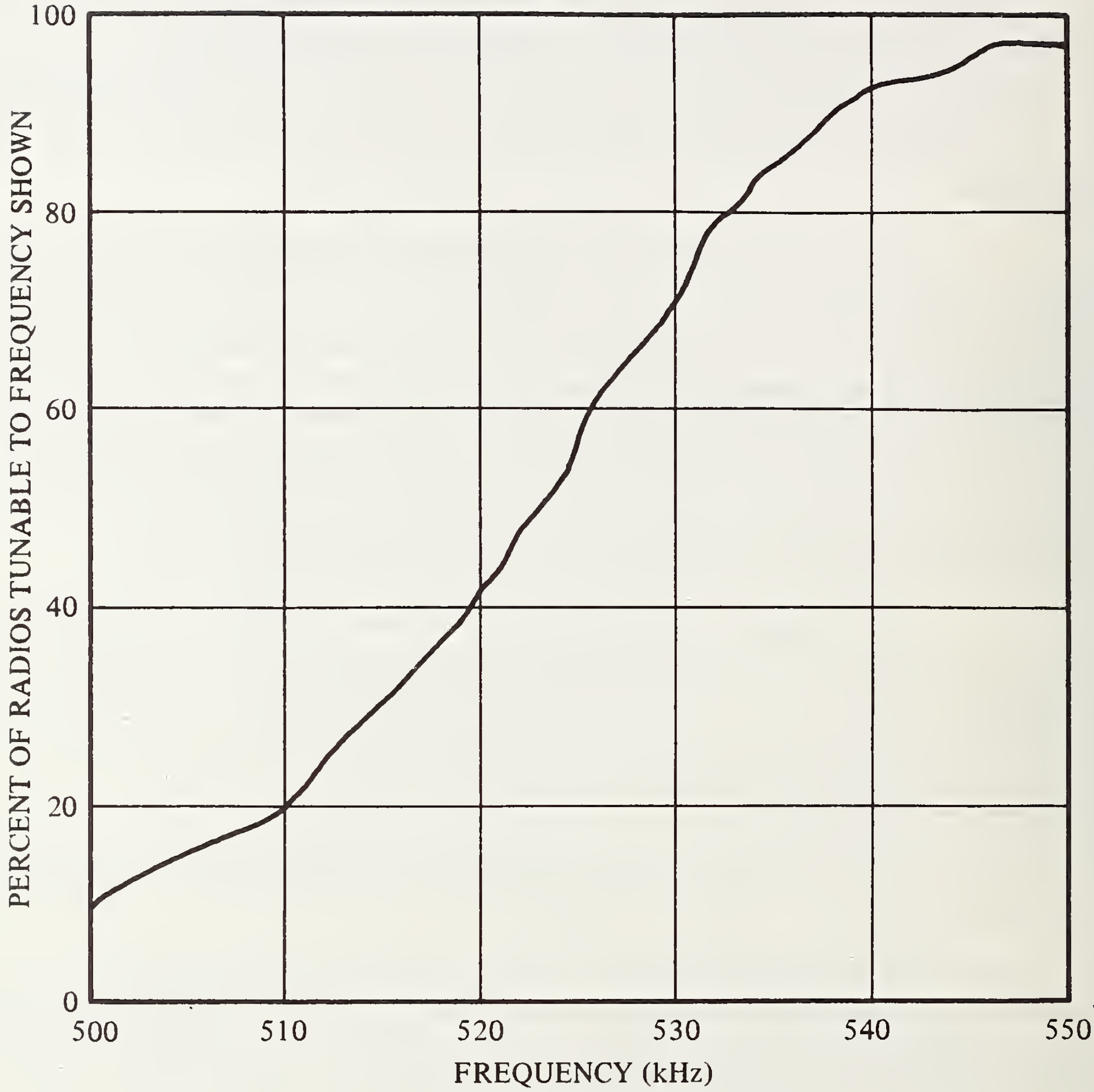


Figure 34. Cumulative Distribution of Lower Tunable Frequencies, Survey I.

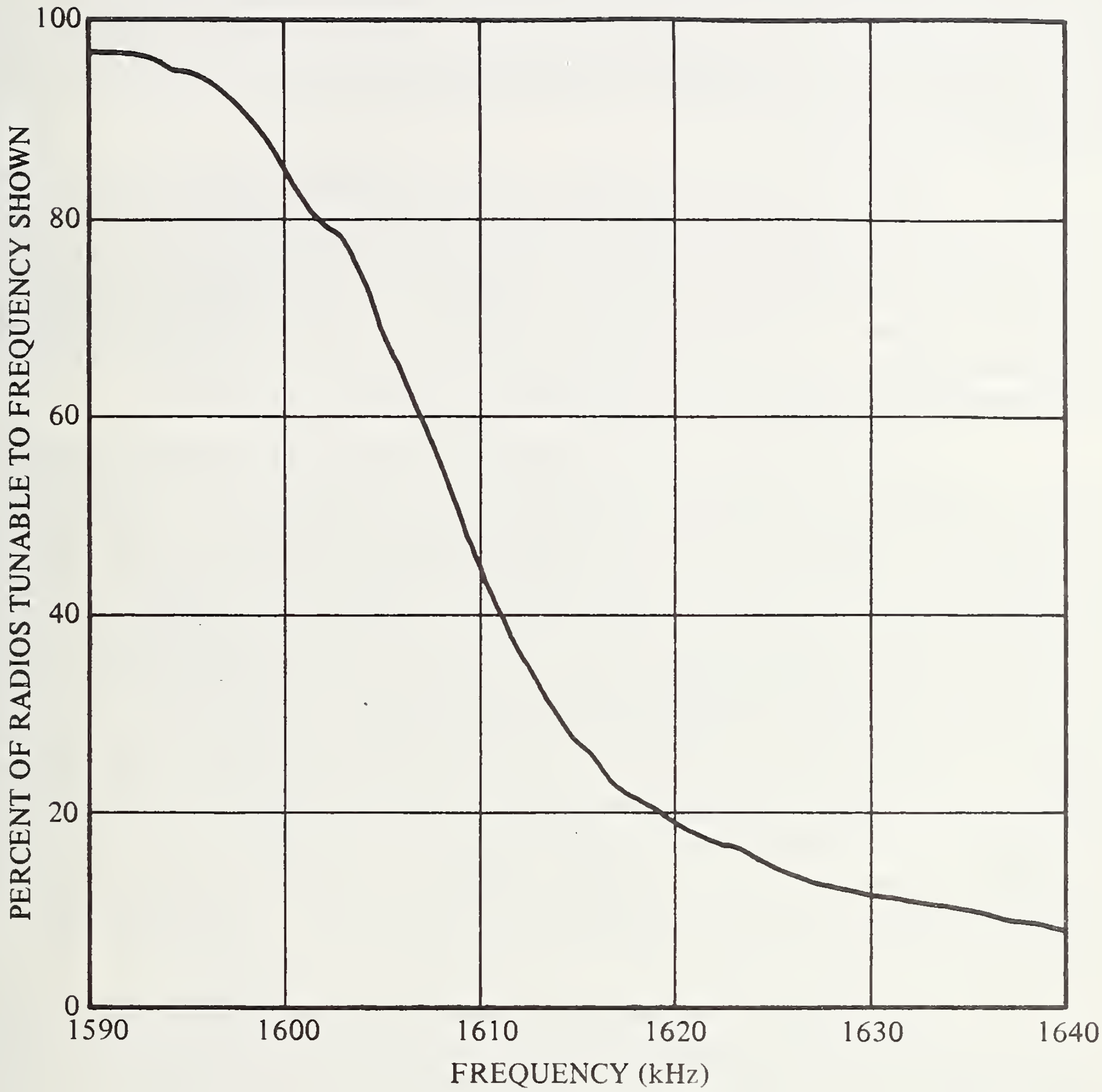


Figure 35. Cumulative Distribution of Upper Tunable Frequencies, Survey I.

The frequency values measured in the Survey I tests as representing tuning limits do not necessarily represent the frequency limits of reception. It will be recalled that the test procedure involved tuning for a maximum audio response (within the receiver passband). Consequently, assuming that the maximum response occurs at the center of the passband, the recorded frequency corresponds to the limit of an AM carrier frequency. Since AM broadcast stations transmit with a ±5 kHz bandpass, it is reasonable to expect that signals can be received at least 5 kHz beyond the measured (lower and upper) tuning limits of every AM radio. This is a very significant factor to consider in relation to the Survey I data, particularly since the objective of the Survey was actually to determine statistics of frequency limits for reception.

The tuning limits of a radio are easily measured and correspond to the limits of the dial reading. Although, as explained above, the tuning limits are not the actual frequency limits of possible signal reception, frequencies outside the tuning limits of a radio are considered here as being out-of-band. The reception of out-of-band signals depends upon a number of factors, the most important of which are receiver bandwidth, bandwidth roll-off characteristics, receiver sensitivity, field strength of out-of-band signal, and presence of interfering signals affecting the automatic gain control (AGC) of the receiver.

As a result of these considerations and at the request of FHWA personnel, a limited investigation was undertaken in December 1973 at Atlantic Research Corporation to determine the receiving capability of out-of-band signals in relation to the tuning limits of AM automobile radios. This survey was made with nine automobiles which had been previously measured in Survey I. At the test location a calibrated field strength of 5 mV/m was established using a signal generator. For each test vehicle the AM radio was first tuned to the lower limit of the band, and the lower tuning limit frequency was measured. Then, the signal generator was tuned increasingly out-of-band while maintaining a 5 mV/m field strength until the modulating tone heard from the radio speaker was no longer considered usable. The resulting carrier frequency was recorded and was considered to be the lower limit of reception. These same procedures were followed for the measurements at the upper end of the band. The maximum out-of-band frequency was considered to be the upper limit of reception. These tests were necessarily subjective in nature; however, the results, presented in Table 4, provide two very important findings. One is the change of tuning limit measured at two different times, and the other is the out-of-band frequency deviation.

With regard to the change in tuning limits, it is seen in Table 4 that two successive measurements of a tuning limit 6 months apart in time normally indicates changes of several kilohertz either higher or lower. Radio 2, however, experienced extreme decreases in both limits, and Radio 5 experienced a large decrease only in the upper limit. Although these data are too limited in number to justify more detailed analysis, they do illustrate that the measured values of tuning limits for automotive radios are not stable and appear subject to random positive or negative drifts with time. It is not known whether these apparent changes in tuning limits are attributable to characteristics of the radio, such as natural aging, vibration and shock, ambient temperature, or to the idiosynchrocies of testing, such as testing technique, accuracy of test equipment, care in tuning to end of band, subjective factors, etc.

Table 4. Out-of-Band Frequency Data, December 1973.

	Lower Tuning Limit			Lower Limit of Reception		Upper Tuning Limit			Upper Limit of Reception	
Car No.	Survey I	December 1973	Δf	December 1973	Δf	Survey I	December 1973	Δf	December 1973	Δf
1	535	534	-1	523	11	1609	1613	+4	1624	11
2	541	510	-31	499	11	1607	1594	-13	1615	21
3	531	535	+4	517	18	1609	1615	+6	1617	2
4	512	515	+3	495	20	1612	1606	-6	1612	6
5	520	517	-3	511	6	1620	1603	-17	1617	14
6	524	527	+3	520	7	1601	1605	+4	1606	1
7	525	520	-5	511	9	1600	1604	+4	1611	7
8	526	524	-2	510	14	1608	1600	-8	1612	12
9	535	535	0	520	15	1623	1625	+2	1646	21
Averages:			-3.6 kHz		12.3 kHz			-2.7 kHz		10.6 kHz

With respect to the measurements of the lower and upper limits of reception, the data in Table 4 indicates many surprisingly large values of out-of-band frequency differences Δf. The lower limit of reception ranged from 6 to 20 kHz below the lower tuning limit with an average out-of-band frequency of 12.3 kHz. Similarly, the upper limit of reception ranged from 1 to 21 kHz above the upper tuning limits with an average out-of-band frequency of 10.6 kHz. As a result, it was found that all vehicles tested in this sample were capable of receiving a usable signal at both test frequencies of 530 kHz and 1606 kHz (with a 5 mV/m field).

Again, the significance of these out-of-band frequency data must be considered in relation to the manner in which they were obtained. The test equipment utilized an audio tone; consequently, these data do not necessarily imply that a usable voice signal could be heard at these same out-of-band frequencies.

The findings of the above limited survey led to further consideration of the significance of the Survey I data. The fact that the radios could generally support adequate reception at relatively high out-of-band frequencies implied that the Survey I data could be modified to provide a more meaningful distribution of frequency limits for reception. The approach taken was as follows.

A comparison of the measured out-of-band receiver sensitivity and the measured in-band sensitivity as a function of frequency provides a general relationship applicable to the AM band of every automobile radio. In particular, the relationship could be applied to those receivers unable to tune to the prescribed test frequencies, and a distribution of relative sensitivity level of receivers at the HAIR system frequency would result. This distribution, after being adjusted to absolute sensitivity levels, would give the percent of radios able to receive the test frequency for a given field strength level. Conversely, the distribution would indicate the minimum field strength required to result in a given percent of the radios to receive the test frequency. Consequently, it appeared that the gathering of appropriate sensitivity data could be used to increase the utility of the Survey I data base considerably.

The success of the above approach, however, was predicated upon the validity of two basic assumptions. First, the sensitivity levels of AM automobile radios were assumed to be relatively similar at any one time and location as they were expected to be determined principally by the local atmospheric noise level. Second, it was assumed that loss of sensitivity would follow a relatively consistent relationship with out-of-band frequency for all radios. (As will be shown, neither of these assumptions were found to be valid.)

Accordingly, Survey II was organized to provide the following quantities of information from at least 50 automobile radios.

a. Lower and upper tuning limits.

b. Sensitivity levels at the lower and upper tuning limits.

c. Sensitivity levels at 530 kHz and 1606 kHz when tuned to these frequencies, or, if out-of-band, to a tuning limit.

A transmitting system using a signal generator, frequency counter, and a power amplifier was set up in the Atlantic Research employees' parking lot. The antennas were located more than 200 feet from the test zone to ensure far field conditions. The transmitter signal was modulated with either a 1000 Hz tone or a recorded voice message. A portable field strength meter was placed on a tripod near the test zone. As with Survey I, drivers entering or leaving the parking lot were asked to stop and cooperate with the testing. Each test lasted 7 to 10 minutes per automobile. No adjustment was made to the automobile antennas.

The measurement procedure was as follows:

a. Tune radio to low end of band.

b. Measure this frequency F_{min}.

c. If 530 kHz is less than F_{min}, then

   (1) Measure the minimum field strength at F_{min} necessary to receive a voice message clearly.

   (2) With the tuning at F_{min}, measure the minimum field strength at 530 kHz necessary to receive a voice message clearly.

d. If F_{min} is less than or equal to 530 kHz, tune to 530 kHz and measure the minimum field strength at 530 kHz necessary to receive a voice message clearly.

e. Tune radio to high end of band.

f. Measure this frequency, F_{max}.

g. If 1606 kHz is greater than F_{max}, then

   (1) Measure the minimum field strength at F_{max} necessary to receive a voice message clearly.

h. With the tuning at F_{max}, measure the minimum field strength at 1606 kHz necessary to receive a voice message clearly.

i. Record the year and make of automobile.

Test data from 54 radios were obtained and analyzed in Survey II. Figure 36 shows the cumulative distribution of the lowest tunable frequencies. It can be seen that 79 percent of the radios could tune below 530 kHz. The distribution of upper tuning frequencies is shown in Figure 37 and also indicates that 79 percent of the radios could tune above 1606 kHz. The results showed that 64 percent of the radios could tune to both 530 kHz and 1606 kHz, while only one radio in the 54 was unable to tune exactly to either frequency.

The lower limit frequencies ranged from 463.0 kHz to 551.4 kHz, and the upper limit frequencies ranged from 1591.0 kHz to 1808.0 kHz.

The somewhat limited sample size of the Survey II data accounts for the uneven shape of the distribution curves of Figures 36 and 37. Although both of these curves could be drawn using a smoother curve without reducing the statistical significance to any appreciable extent, no smoothing has been done in order to preserve accuracy of the data.

It is instructive to present a comparison among corresponding distribution curves of the frequency tuning limits obtained from various surveys. Figures 38 and 39 present comparisons among the tuning limit data from Survey I, Survey II, and the FCC survey mentioned earlier. The curves of the lower tuning limit show reasonably good agreement. The spread in the percent values at any frequency seldom exceeds 10 percent, particularly between the Survey I and Survey II curves. The size of the FCC data sample was nearly the same as for the Survey II sample; however, the measurement technique of the FCC survey is not known.

There is considerably less agreement among the curves for the upper limit data. The Survey I and II curves have similar shape, but are somewhat uniformly displaced by about 10 percent on the ordinate scale. Detailed examination of the original data revealed that the Survey I sample contained an unusually high number of frequencies below 1600 kHz. Specifically, 11 percent of the Survey I radios tuned to less than 1600 kHz, whereas less than 4 percent did so in the Survey II sample. This difference raises the cumulative distribution of the Survey II data by about 10 percent.

The FCC distribution curve in Figure 39 deviates excessively above 1613 kHz; however, it will be recalled this sample contained only 17 points.

Some degree of spread is expected with any limited sample. To illustrate, some simple statistical theory has been applied to the Survey II data in the following manner. For each of the lower and upper limit data samples, an estimate of the mean frequency was calculated using the expression

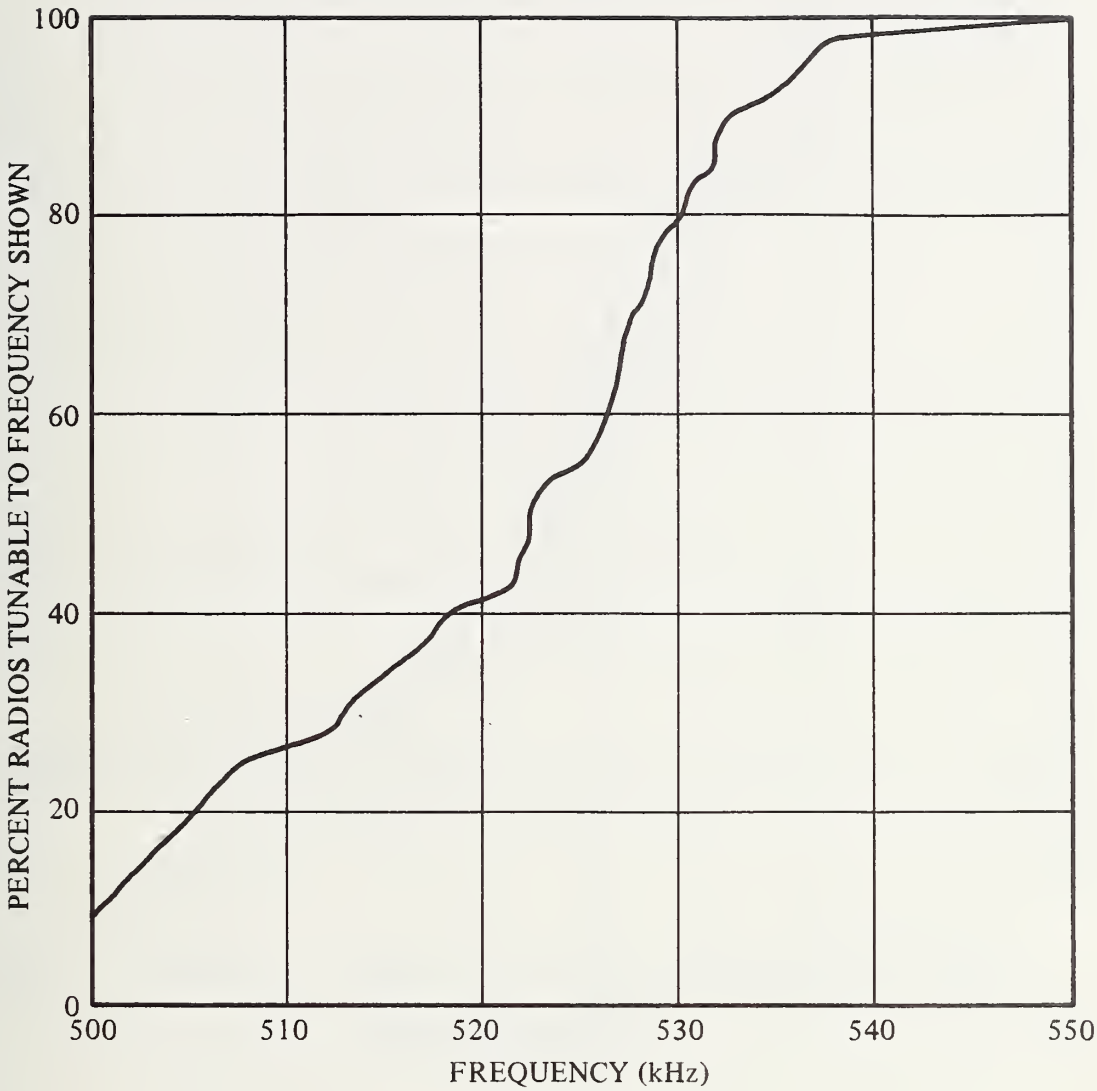


Figure 36. Cumulative Distribution of Lower Tunable Frequencies, Survey II.

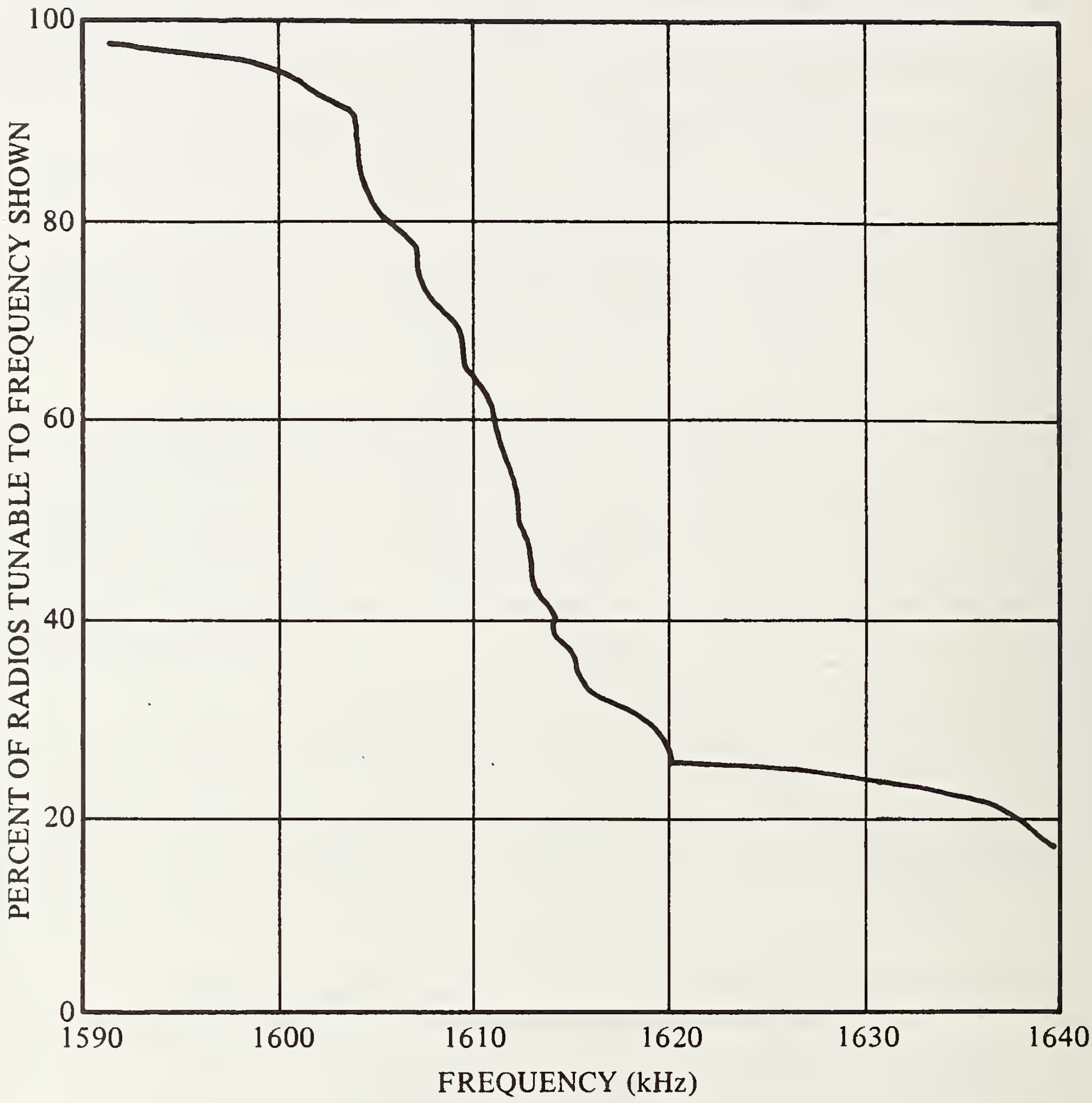


Figure 37. Cumulative Distribution of Upper Tunable Frequencies, Survey II.

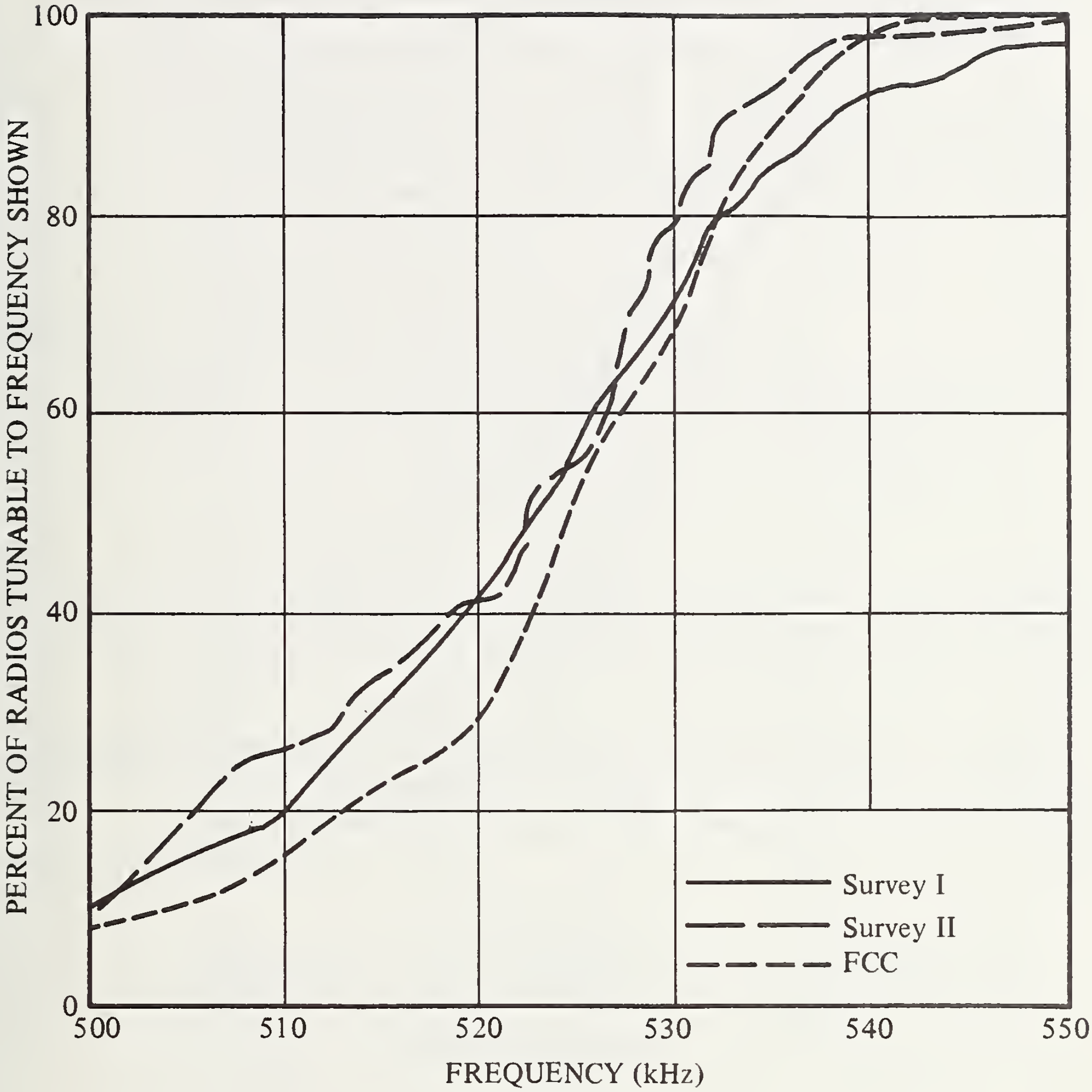


Figure 38. Comparison of Distributions of Lower Tunable Frequencies.

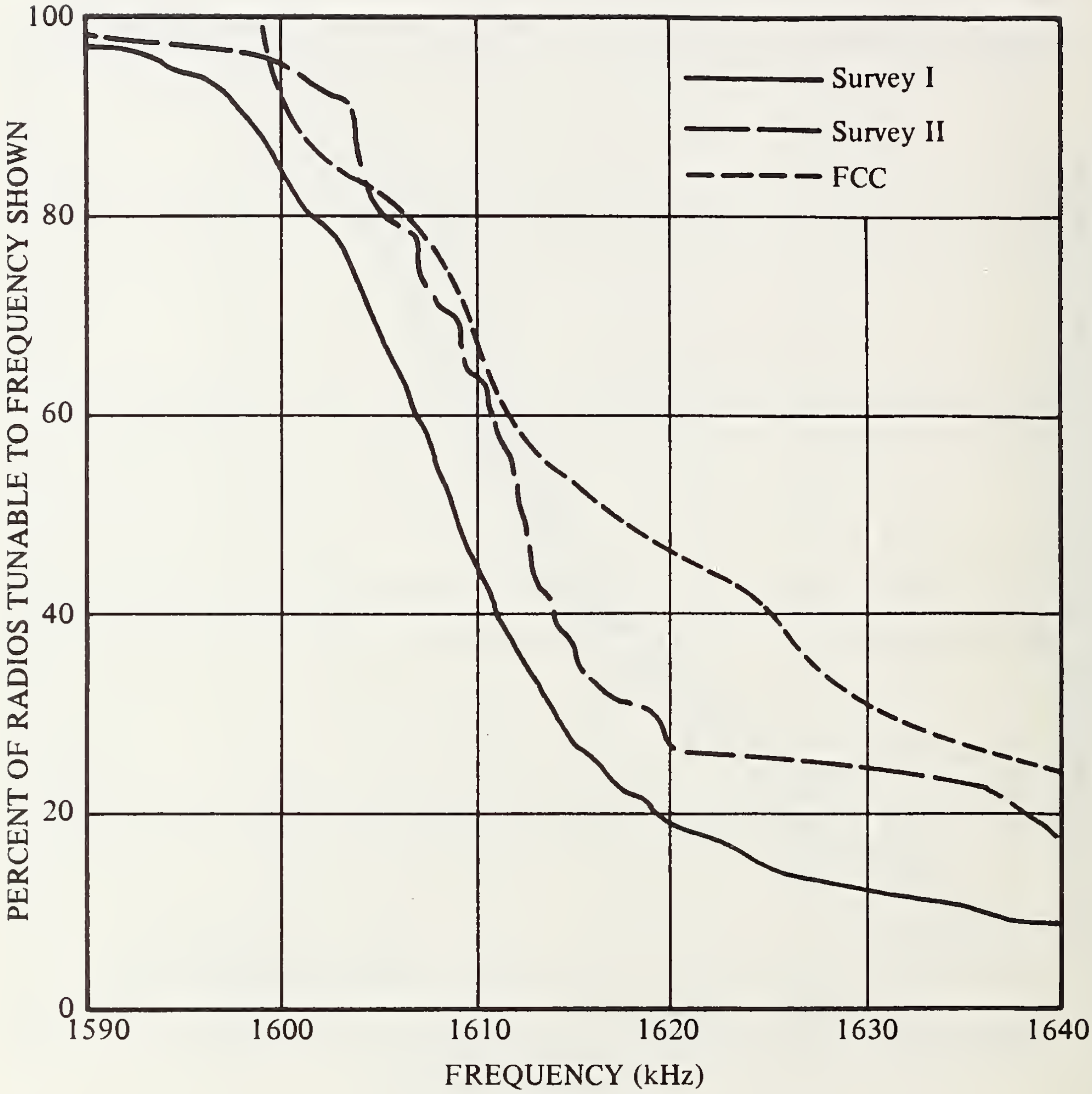


Figure 39. Comparison of Distributions of Upper Tunable Frequencies.

$$\overline{F} = \overline{f} \pm t \frac{s}{\sqrt{n}}$$

where

$\overline{F}$ = mean frequency for all radios

$\overline{f}$ = measured mean frequency from sample

t = student's t value for probability p and n-1 degrees of freedom

s = standard deviation of data in sample

n = number of data points in sample

For the Survey II samples, the following quantities were measured.

Quantity	Lower Limit Sample	Upper Limit Sample
$\overline{f}$	519.5 kHz	1621.7 kHz
s	17.1 kHz	25.8 kHz
n	53	53

All data points in the lower limit sample were included for these calculations, but the highest point of 1808 kHz was eliminated in the upper limit sample for these calculations.

The t value for a probability of 0.80 that it will not be exceeded (without regard to sign) is 1.30, and for a probability of 0.90 is 1.67, for 52 degrees of freedom.

Substitution of the above values into the expression gives the following values of $\pm t\, s/\sqrt{n}$.

Probability	Lower Limit (kHz)	Upper Limit (kHz)
0.80	±3.0	±4.6
0.90	±3.9	±5.9

Each of these values represents a confidence interval and indicates the accuracy of the measured sample mean relative to the "true" population mean. For example, there is a probability of 0.80 that the measured mean of 519.5 kHz lies within 3.0 kHz of the mean lower limit frequency of all the AM band automobile radios. The confidence intervals pertain only to the mean or average frequency for each sample and are indicative of the statistical reliability of the data. Although the mean frequency may be of little or no

interest it is perhaps the most stable statistic and thus has the smallest confidence interval for a given probability. Consequently, it is expected that other points of statistical measure for the same data, such as the frequency at which 90 percent of the radios can be tuned, will have larger confidence intervals than the values shown above. This brief statistical analysis does point out that there is a reasonable amount of discrepancy between corresponding curves shown in Figures 38 and 39 due simply to the fact that each curve represents a limited sample of a highly variable statistic, namely the frequency tuning limit.

Aside from the statistical variations, the discrepancies among the various corresponding survey curves may also be attributed to factors such as inconsistent measuring techniques, uncalibrated frequency measurement, ambient temperature, presence of interfering signals, and various subjective factors.

An attempt was made to determine a possible source of difference between the Survey I and Survey II data by locating and analyzing corresponding data of radios common to both surveys, as was done with the December 1973 survey discussed earlier. Fifteen such automobiles were located, and the change between corresponding tuning limit frequencies measured by each survey were calculated. For the lower tuning limit the difference between the Survey II minus the Survey I readings ranged from -12.8 kHz to +10.6 kHz with one unusual value of -53.8 kHz. The average change of lower tuning limit was -0.34 kHz, excluding the -53.8 reading. For the upper limit data, the frequency change ranged from -4.0 kHz to +9.2 kHz with two unusual readings of 28.7 kHz and 61.3 kHz. Excluding these two readings, the average change in the upper tuning limit was +0.55 kHz. Thus, it appears that the change in tuning limit of a radio is relatively random, positive or negative with time, and no particular trend is seen. These findings are consistent with the corresponding results reported earlier for the December 1973 survey.

The results of the sensitivity data from Survey II have been analyzed and are presented as cumulative distributions of minimum field strength. Figure 40 presents the cumulative distribution of receiver sensitivity in terms of field strength at 530 kHz for 52 radios. Only eight radios could not tune directly to this frequency and thus had to receive out-of-band. These cases are shown by circles along with the amount of frequency deviation out-of-band. The end of the horizontal line marks the sensitivity when receiving the lowest tunable (in-band) frequency. In most cases there is loss of sensitivity due to tuning out-of-band, but, interestingly, a few cases resulted in improved sensitivity when out-of-band. This appears to have been due to the effect of interfering stations at the lowest tunable frequencies. The sensitivity data are seen to range from 14 microvolts per meter to 1 millivolt per meter, a spread of nearly 40 dB. It will be noted that half of the out-of-band measurements occurred at the highest field strengths and half at the lowest field strengths.

The distribution of sensitivity of Figure 40 shows, for example, that approximately 90 percent of the radios could receive 530 kHz at a signal level of 300 microvolts per meter, and nearly 100 percent of the radios could receive 530 kHz with a 1 millivolt per meter field.

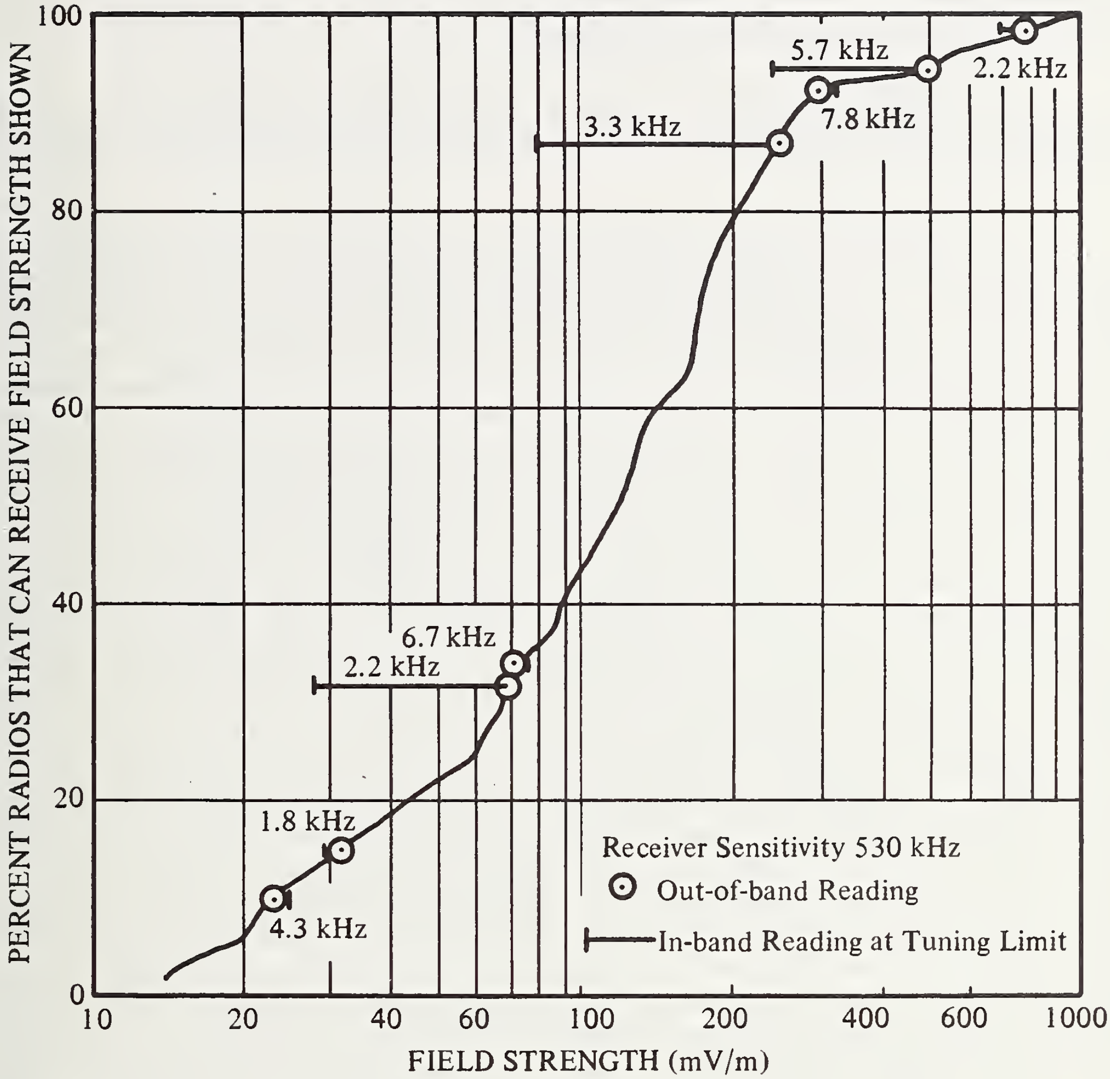


Figure 40. Cumulative Distribution of Receiver Sensitivity at 530 kHz.

The cumulative distribution of sensitivity at 1606 kHz for 54 radios is presented in Figure 41. Within these data ten radios could not tune to 1606 kHz, as indicated by the circled data points. It can be seen that nine of the out-of-band readings occurred in the upper half of the (logarithmic) sensitivity range, and one occurred at a very low sensitivity level. The spread of these sensitivities ranged from 27 microvolts per meter to 3.9 millivolts per meter, more than a 40 dB spread.

Figure 41 indicates, for example, that 90 percent of the radios could receive 1606 kHz with a field strength of 0.8 millivolt per meter, and 100 percent with 4 millivolts per meter.

There are two major observations of interest here that can be made from the Survey II sensitivity data. First, receiver sensitivity is not a relatively fixed value among different receivers. The surprisingly wide spread of sensitivity levels of approximately 40 dB for in-band signal reception indicates that the initial assumption that the receiver sensitivities of AM radios are similar at any one time and location is not true. Second, there is not a uniform relationship between loss of sensitivity and out-of-band frequency. Although Survey II provided very few out-of-band data points, there appears to be no correlation between the loss of sensitivity and the out-of-band frequency as can be seen in Figures 40 and 41. The lengths of the horizontal lines correspond to loss of sensitivity (for lines that extend to the left of the circle). The associated out-of-band frequency shown on each line does not correlate with the length of the line. Consequently, the second principal assumption that there is a consistent relationship between loss of sensitivity and out-of-band frequency is also found to be invalid. As a result, it is apparent that the original intent of Survey II cannot be fulfilled; that is, to determine the loss of sensitivity versus out-of-band frequency for purposes of enhancing the utility of the Survey I data base. However, the Survey II findings are extremely important, for they have provided a more reliable basis for determining the probability of receiving a HAIR frequency channel. It is apparent that the tuning limit frequency of an AM radio is not a satisfactory measure of how well the radio might receive a given field strength at a frequency inside or outside the tunable band. The Survey II data indicates the importance of considering receiver sensitivity. The reception of signals at frequencies within the tuning range of a receiver is not guaranteed unless the field strength exceeds the sensitivity level of the particular receiving system. Similarly, signals that are outside the tuning range may be received provided the field strength is sufficiently strong. As a matter of fact, in the Survey II tests both 530 kHz and 1606 kHz were received satisfactorily by every automobile radio tested except for one case. This exception involved a radio having a lower tuning limit of 551.4 kHz, and insufficient field strength was available to provide reception, if at all possible, at 530 kHz.

In conclusion, it appears that the most reliable estimate of the percentage of AM radios which could receive a given field strength at a given frequency can be obtained from the statistical distribution of receiver sensitivity levels (in terms of field strength) measured at the given frequency. The desired percentage could be achieved by providing the indicated field strength as a minimum throughout the coverage zone.

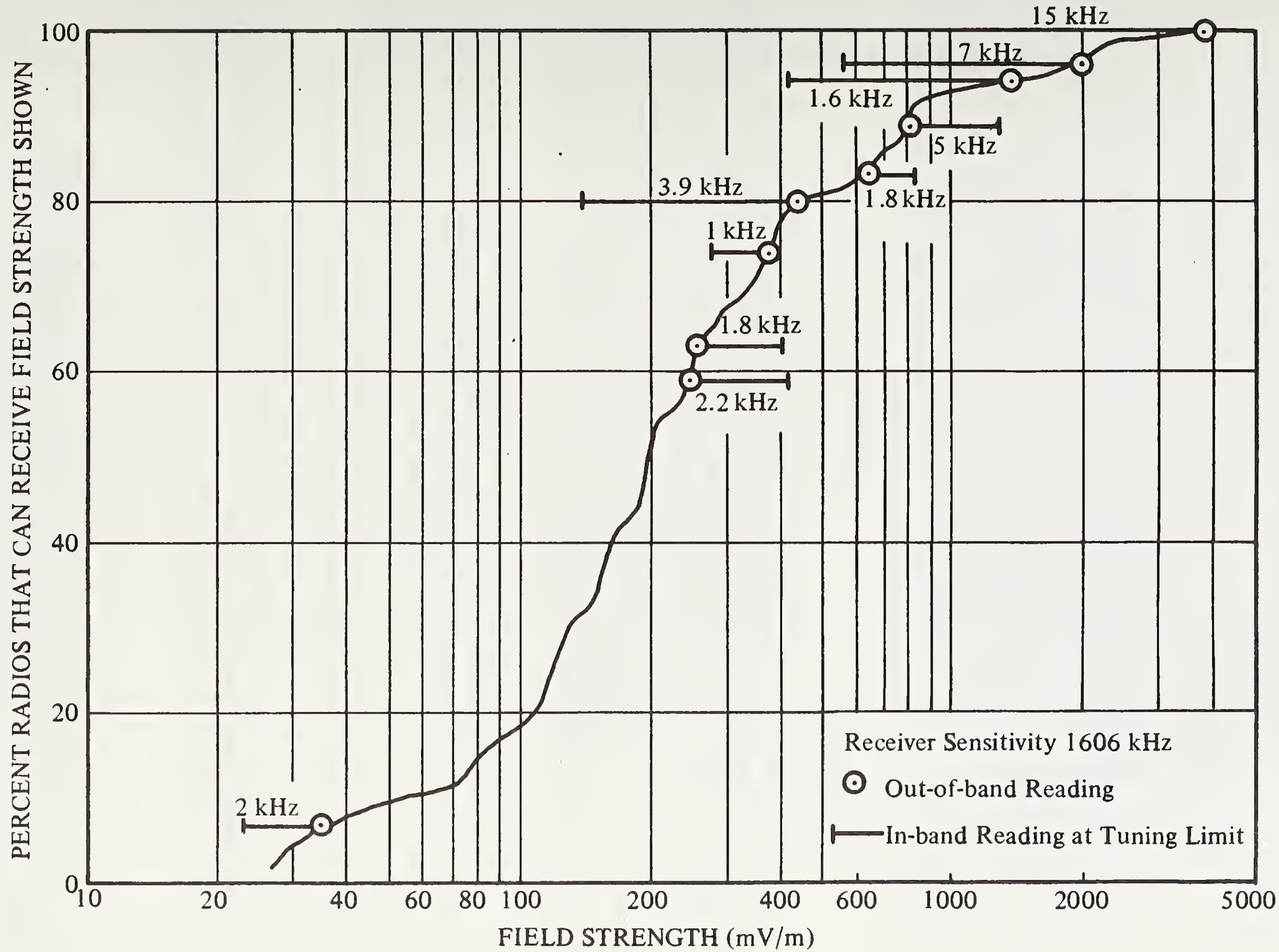


Figure 41. Cumulative Distribution of Receiver Sensitivity at 1606 kHz.

6.0 FCC APPLICATIONS

6.1 Introduction

This section of the final report deals with the regulatory and allocations aspects of a fully implemented Highway Advisory and Information Radio (HAIR) system for the United States. Building upon the results of the prototype development work conducted under the current contract, this section will serve to identify logical next steps to be taken in moving to the interim stage wherein existing automobile radios will be served by a system of regional and, finally, nationwide HAIR transmitters. The emphasis in the discussion contained in this section will be on those steps which relate to establishing a permanent government authorization for the proposed radio transmitters which will be required to be placed in operation throughout the country.

6.2 Background

It has been demonstrated that the prototype Highway Advisory Information Radio system can function and is technically feasible for operation slightly above and slightly below the standard AM broadcast band (540 to 1600 kHz). The transmitter frequencies used in this program were 530 kHz and 1606 kHz with a single frequency assigned to each direction of traffic flow. Authority for transmissions on these frequencies was granted to Atlantic Research Corporation by the Federal Communications Commission (Appendix F). Call sign KC2XCM was assigned for experimental work in connection with the HAIR program at 530 kHz and 1606 kHz using 15 watts of power into the antenna. Geographic use of this station was limited to Fairfax County, Virginia.

It should be noted that brief consideration was given to the use of nonlicensed, low-power transmissions which would be compliant with part 15 of the Rules and Regulations of the FCC. It was determined that such reduced radiation levels would not be effective in reliably providing this service even though "lossy" coaxial cable antennas placed along the roadway would require coverage of only a very limited range. This matter was treated extensively by Halstead and Mazzola in their work reported in 1969.[1]

The survey and test program using the prototype system in Fairfax County demonstrated that, at least in this part of the U.S., the system was compatible with other licensed users on adjacent frequencies. Furthermore, the existing automobile population

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[1] Halstead, William S. and Mazzola, Robert A., "Highway Communication Using Wideband Cable and Inductive Transmission Methods," IEEE Transactions on Vehicular Technology, Vol. VT-19, No. 1, February, 1970.

would, generally, be able to receive signals at the edges of the AM broadcast band. This is important since a transition period would necessarily take place in moving to a fully automatic HAIR system installed nationwide in all automobiles. For this very important reason, the HAIR system must be compatible with current automobile radio receivers insofar as is practical. Certainly, the time may come when a second generation of HAIR would involve the FM band (88 to 108 MHz) or some entirely different set of frequencies. Even today a strong move is being made to require all automobile radios in new cars to be AM/FM models. This activity largely influenced by commercial FM broadcasters could affect future HAIR systems. At the present time, the edges of the AM band represent the most viable possibilities for the first generation of Highway Advisory Radio systems because of three major considerations: (1) AM radios are in wide use as automobile receivers (about 92 percent of all automobiles have them), (2) apparently spectrum space does exist in these regions, (3) a large percentage of existing automobile receivers can receive far enough beyond the broadcast band limits to accept HAIR signals.

6.3 The Regulatory Environment

Should the HAIR system be operated by local, state or regional governmental bodies, licensing of the transmitters will be within the jurisdiction of the Federal Communications Commission (FCC). On the other hand, should HAIR be operated by the Department of Transportation or some other federal agency, licensing and allocation responsibility would rest with the Interagency Radio Advisory Committee (IRAC). It is assumed that HAIR will eventually be operated by each state's highway department under the guidance of DOT. In fact, it may come to pass that HAIR will be a requirement imposed upon each state as a condition of receiving matching money for new highway construction. If HAIR is, indeed, operated by and licensed to state highway departments, regulation and allocation responsibility would probably fall to those branches of the FCC involved in administering the *Special Emergency Radio Service* or the *Local Government Radio Service.* Most likely the Local Government Radio Service would control this new radio activity since radio call boxes (Highway Emergency Communications Systems) are already in this Service.

6.4 Spectrum Availability

It would appear that 530 kHz and 1606 kHz are generally acceptable frequencies for the HAIR system providing that transmitted energy for each road side unit be confined, insofar as may be practical, to the highway itself. To a certain extent this is at odds with the definite need to create a significant field through which the automobiles using the highway will pass. A weak HAIR signal might be swamped out by other signal sources, beats or power line noise.

Current, licensed users do occupy the 530 and 1606 frequencies, so congestion related interference is a potential problem for consideration by HAIR as well as other users. Again, this suggests careful selection of power levels and transmitting antenna patterns for HAIR. This, in turn, suggests further development of the "lossy" coaxial cable system used in the prototype program. Rather than a cylindrical horizontal polarization, a vertically polarized directional pattern should be sought.

Radio beacons appear to constitute the largest body of signals residing in the 530 kHz region.

The band between 1605 kHz and 1610 kHz is allocated for the operation of remote broadcast pickup. However, it does not appear that much use is made by broadcasters in this band even though licenses have been issued for this purpose. Obviously, telephone lines and other means are more often used for this purpose since transmissions in the 1605 to 1610 kHz region would be subject to natural electrical interference and power line noise. Broadcasters typically desire better quality and reliability than that which this band would provide.

No significant interference problems were discovered during the course of the prototype testing program. Since the system was only operated in a very small part of Fairfax County, this experimental data cannot be made to demonstrate assurance that problems will not exist elsewhere in the United States or near its borders. Such assurances can only be obtained through careful research as to locations, frequencies and powers of U.S. stations and nearby Mexican or Canadian stations licensed to operate on or adjacent to these two frequencies. Perhaps more to the point, a program of field strength surveys conducted over a representative sample of the U.S. highway system should be undertaken. Such surveys could include samples taken in motion over highways near the coasts and borders as well as near major population centers and in rural areas.

The data collected through research or the more specific survey method would be a fundamental step prior to requesting new rule making for permanent assignment of HAIR to these frequencies.

6.5 Compatibility with Broadcast Stations

While it did not present a problem in the test period of the HAIR system in Fairfax County, there are radio broadcast stations operating on the frequencies of 540 kHz and 1600 kHz elsewhere in the U.S. and its neighboring countries. The adjacency problem could be particularly troublesome in the case of the 1606 kHz HAIR signals transmitted along highways that pass broadcast stations operating on 1600 kHz. There are seventy-five broadcast stations across the U.S. assigned to 1600 kHz.

Without further investigation as to the field strength contours presented by stations on 1600 kHz and their spatial relationship to proposed HAIR system routes, it is difficult to predict the severity of the problem that might arise in the implementation of a national HAIR system. Also affecting the severity of the problem are the selectivity of existing automobile radios and the level of "containment" that might be established through improvements to the buried cable antenna system.

It would appear that the broadcast compatibility problem deserves serious investigation (along with the spectrum availability situation) prior to soliciting the FCC on the matter of permanent licensing of HAIR at the two proposed frequencies.

6.6 Other Potential Problems

The rights of way for highways will parallel or cross each other in many locations throughout the country. The potential for heavy power line noise exists for HAIR just as it does for standard broadcast reception in a moving vehicle. The problem exists and cannot be eliminated all at once. What must be done is to design the system so as to avoid transmission of important information in the zones where power lines cross the roadway. Where the power lines parallel the roadway the only partial solution is to handle each situation as it presents itself. This is to say, wherever and whenever excessive power line noise is found to exist, highway radio engineers must work in cooperation with power company personnel to eliminate or reduce the disturbance. Cracked or dirty insulators and corona discharge from the sharp bends in conductors are the most prevalent noise sources in high voltage transmission systems. These difficulties are also the easiest to correct.

Unlicensed radio operators present still another potential problem to the reliable operation of HAIR. Certainly, this problem would occur, to some extent, at whatever frequency was chosen for HAIR. Unlicensed operators often select frequencies near the broadcast band for the very same reason that HAIR has put forth the abundance of existing receivers. This problem would, again, have to be treated on a case-by-case basis. When an illegal transmitter is detected it will require the use of triangulating receivers to locate. The FCC, of course, is charged with the responsibility of eliminating such problems. However, detecting such illegal stations in practice might prove difficult since it is unlikely that a passing motorist will take the trouble to inform the appropriate official of the existence of the problem. More likely, highway radio maintenance crews will have to periodically "sweep" the area for potential power line problems, illegal stations and all other potential sources of interference.

6.7 Discussion

In its February 1, 1972, Memorandum Report and Order in regard to the use of broadcast frequencies by the Los Angeles Department of Airports for "roadside radio," the FCC indicates that the Commission proposed to undertake, at that time, an investigation into the use of frequencies just above the broadcast band for this purpose. If that investigation has been completed, the results have yet to be made public. Nevertheless, the attitude of the FCC would appear favorable to the concept embodied by HAIR. Since the potential for service in the public interest is so high, it would seem that if a solid technical case can be made for use of 530 kHz and 1606 kHz, the Commission would react positively to such a request for Rule Making.

Earlier in this section the matter of potential noncompatibility of the use of 1606 kHz by HAIR facilities located in the same general region as a broadcast station on 1606 kHz. Should this problem be insoluable, consideration might be given to the use of a single frequency HAIR system rather than a dual frequency (south-bound, north-bound) system. Since it has been shown that radiation of the buried antenna drops off sharply at the end of each coaxial cable section, it might be possible to use alternating sections of

buried antenna for each direction of traffic flow. This would mean that messages for those going one direction would also be heard by those going the opposite way. Perhaps the format of messages could be adjusted to compensate for this alternate message configuration in those few parts of the country where the incompatibility exists.

In summary, our findings suggest a parallel course of further study concurrently undertaken with increased FCC interface activity. These major points are described further in Section 8.0, Recommendations.

7.0 CONCLUSIONS

This report has presented the results of a Department of Transportation program for the research, development, test, and evaluation of a Highway Advisory Information Radio (HAIR) system. The conclusions and principal findings of this study are presented in this section.

a. Digital coding using two audible tones can be used with voice messages from a roadside radio transmitter for controlling the operation of automatic radio receivers in automobiles. The voice content of the messages can also be received with commercial automotive receivers.

b. Automatic radio receivers with solid state logic decoding circuitry designed for use with the HAIR system can be manufactured in production quantities for less than $50 per unit depending upon the lot quantity.

c. The elements of the automatic receiver for the HAIR system may be packaged in different arrangements to suit particular needs. Three models were developed in this program. Two are the Adaptor and Portable units, each of which are complete HAIR receivers in individual packaging. The third is an Integrated unit in which the HAIR receiver is mounted inside the case of a commercial automotive receiver.

d. A subaudible tone transmitted continuously in the radio message can be used to provide an automatic means for enabling the decoding circuitry of HAIR receivers when located within the radio zone of coverage.

e. Single-stage, tuned antenna traps as used in the HAIR Adaptor and Integrated receivers to provide isolation between the automatic and commercial radios connected to a common antenna have shown to be inadequate for general use. The tuning of these traps can change with dial tuning of the commercial receiver and also with the make of commercial receivers used.

f. A roadside transmitting system consisting of one or more vertical whip antennas at suitable spacings can provide continuous radio coverage over a section of the highway at AM broadcast frequencies with 10 watts or less of transmitter power. The length of the coverage zone depends largely upon the efficiencies at each antenna and the sensitivities of the receivers. At 530 kHz, one whip antenna can provide more than 1 millivolt per meter field strength throughout a 4000-foot zone with 4 watts of transmitter power, and at 1606 kHz one whip antenna can provide more than 1 millivolt per meter throughout the zone with 1 watt of transmitter power.

g. Cable antennas buried along the side of the highway offer an alternate means of providing radiation to vehicles within a message zone. Limited testing with two commercially available models of cable antennas have demonstrated their compatibility with the HAIR system.

h. A survey of commercial AM receivers in passenger vehicles has shown that the ability of automotive radios to receive either 530 kHz or 1606 kHz does not depend significantly upon the tuning range of the radios. Rather, the sensitivities of the receiving system versus field strength of the signals determines the likelihood of reception. A survey of 54 automobiles resulted in only one radio unable to receive one of the test frequencies; all other vehicles could receive both frequencies at some field strength, whether in-band or out-of-band.

i. Statistical analysis of the survey data indicates that approximately 90 percent of the radios could receive 530 kHz at a signal level of 300 microvolts per meter and nearly 100 percent of the radios could receive 530 kHz with 1 millivolt per meter field. Similarly, 90 percent of the radios could receive 1606 kHz with a field strength of 1 millivolt per meter and 100 percent with 4 millivolts per meter. The meaning of sensitivity used here is the minimum field strength at which an intelligible voice message can be heard from the radio speaker.

j. Field tests of the Hair system at a test site on the Dulles Access Highway, Virginia, generally showed satisfactory performance of the automatic receivers at 530 kHz with all antenna systems.

k. At 1606 kHz the HAIR receivers showed excellent performance for all antenna systems with the following exception. With the Andrews RADIAX cable the receiver did not operate reliably in the inside (far) lane of the highway.

8.0 RECOMMENDATIONS

A number of recommendations for improving the operational performance of the development HAIR system and also for furthering the development of the highway advisory radio concept are presented below.

a. Consideration should be given to eliminating the use of the subaudible tone as a technique for automatically enabling HAIR receivers when in the vicinity of a radio message zone. Alternate techniques are possible; for example, the transmission of a dual-tone burst every 10 seconds could reset a delay timer. Loss of two consecutive bursts could result in automatic disabling of the receiver.

b. In order to increase the reliability of message capture by the automatic receivers it is recommended that consideration be given to the installation of a delay circuit in the logic decoder circuit board which will prevent disabling due to momentary disruptions of the subaudible tone. The delay time may be set arbitrarily to a practical value such as 10 seconds, indicating that the receiver automatically disables only after a continuous loss of the subaudible tone for a period exceeding 10 seconds.

c. Design improvements in the antenna isolation circuit are needed for the Adaptor and Integrated receivers to replace the existing antenna traps. An active component such as a transistor in the antenna line would provide the needed isolation; however, such a device may be subject to generating intermodulation signal products that could interfere with normal reception.

d. Further study should be given to the design and development of buried cable antennas suitable for use in the HAIR system at standard AM broadcast frequencies. The radiation factor in dB of power radiated per 1,000 feet of cable should be optimized so that minimum (unradiated) power is absorbed in the terminating load, while distributing the radiated field uniformly along the full length of the cable. Ideally, the radiation factor should increase with

distance along the cable. Further, the cable should be of a practical design, easy to install, and relatively inexpensive.

e. It is recommended that an evaluation be made of public motorists' reaction to using various types of AM radios capable of receiving HAIR messages. In particular, a survey should be taken of motorists' desires in using automatic receivers versus standard (nonautomatic) receivers, which require manual tuning to the HAIR frequencies. In order to obtain these data, a pilot study involving one or more test zones along selected highways where information radio systems are needed could be established and evaluated by motorists volunteering to utilize the service with government furnished receivers. The types of receivers that may be evaluated include: (1) the three types of automatic HAIR receivers developed in this program, (2) nonautomatic receivers such as the standard automotive receiver, and (3) a small, transistorized portable receiver that is fixed tuned to the two HAIR frequency channels and is manually controlled.

f. Additional sensitivity measurements of automotive receivers are needed to improve the statistical reliability of the existing data base needed for determining the minimum required field strength to operate a given percentage of receivers.

g. It is recommended that a similar program involving the survey, design, development and testing of a HAIR radio system applicable for use with the FM broadcast band be undertaken in consideration of the increasing use of automotive FM radios.

h. A policy determination must be made as to which governmental organization or agency shall be the license holder for each of the HAIR stations throughout the U.S. This determination will help to establish whether the FCC or IRAC will administer and regulate the use of frequencies.

i. It is recommended that the major effort toward permanent licensing and further research for HAIR be restricted to consideration of the AM broadcast "edge" frequencies (530 kHz and 1606 kHz).

j. A continuing dialogue with the FCC should be started so as to keep the Commission up to date on HAIR related activities. These sessions would also serve to uncover the results of the FCC in its own probes related to the feasibility of using broadcast band edge frequencies for other services.

k. Experimental and theoretical research should be undertaken to develop an improved buried antenna system for HAIR. Work would be directed at ways of "containing" the RF energy over the roadway through development of better directional characteristics for the antenna systems.

l. Further survey work and review of licensing records should begin immediately to ascertain the level of existing congestion of the 530 kHz and 1606 kHz frequencies. This data would be used to determine possible modifications needed for the HAIR system, its antenna cable and current radio frequency allocation regulations.

m. In conjunction with the survey and record research described above, the matter of HAIR's compatibility with existing broadcast stations must be determined. This work would include an analysis (by sampling) based on the selectivity of existing automobile radios determined under this contract and a survey/measurement program to establish the field strength levels that would be expected from existing 540 and 1600 broadcast stations over proposed HAIR routes.

n. Should the two frequency HAIR systems prove not feasible in certain parts of the country, consideration should be given to how a single frequency system could be used in these geographic areas. This work involves both the functional as well as technical aspects of HAIR.

o. Over the period of the aforementioned research, an experimental license should be kept in effect for the HAIR prototype on a nationwide test and evaluation basis. This would support the survey work by providing a method whereby on-site tests could be conducted in areas of the country where compatibility appears doubtful.

p. Following the conclusion of the majority of the work outlined above and predicated on positive findings thereof, the FCC should be petitioned to provide new Proposed Rule Making for HAIR on a permanent, nationwide basis.

APPENDIX A

LABORATORY TEST PLAN

ENCODER AND TAPE RECORDER CONTROL

PURPOSE

The purpose of these tests is to demonstrate the proper functioning of the Encoder. This test has been designed to test all of the important parameters associated with the generation of the necessary codes and to demonstrate the application of voice along with the codes. Further, the tests will demonstrate the Encoder's ability to command the Spotmaster 400A Tape Recorder to start-stop when codes are to be recorded. The temperature tests are designed to measure the survivability of the Encoder when stored at extreme temperatures and to operate over the required temperature range.

SPECIAL INSTRUCTIONS

A. Care must be exercised to ensure that all grounds are properly made and that there is no noise being introduced into the Encoder input or output circuits.

B. When testing the Encoder at its temperature extremes, the unit must not be operated until it has returned to within its normal operating range and stabilized. Allow at least 30 minutes at operating temperature before turning the unit on.

TEST EQUIPMENT REQUIRED

1. Tektronix 7613 Storage Oscilloscope
2. Spotmaster 400A Tape Recorder
3. Hewlett-Packard Frequency Counter.

TEST 1

TONE FREQUENCY ACCURACY

Requirement

The tone frequencies being generated within the Encoder shall operate at the frequencies of 82.5 Hz (subaudible tone), 852 Hz, and 1477 Hz. Each of these tones must be within ± 1% of the required frequency.

Procedure

1. Interconnect the equipment as shown in Figure 42.
2. Turn on all equipment.
3. Remove the top cover on the Encoder.
4. Connect the input of the Hewlett-Packard frequency counter to the audio output terminals of the Encoder on the barrier strip located on the left side.
5. Adjust the counter to count for a 10-second period.
6. Measure and record the frequency of the subaudible tone. Observe a minimum of three readings.

   (H_3) Frequency 1)82.4 2) 82.4 3) 82.4 Sensitive to vibration (can go to 87).

   Percent 0.12 %
7. Connect the frequency counter to Pin 3 of IC 14.
8. Measure and record the frequency. Note: Record the average of a minimum of three readings.

   (H_3) Frequency 1) 858.3 2) 858.7 3) 858.9 Not sensitive to vibration

   Percent 0.775 %
9. Connect the frequency counter to Pin 3 of IC 15.
10. Measure and record the frequency. Note: Record the average of a minimum of three readings.

    (H_3) Frequency 1) 1479.1 2) 1479.0 3) 1479.1 Not sensitive to vibration

    Percent 0.142 %

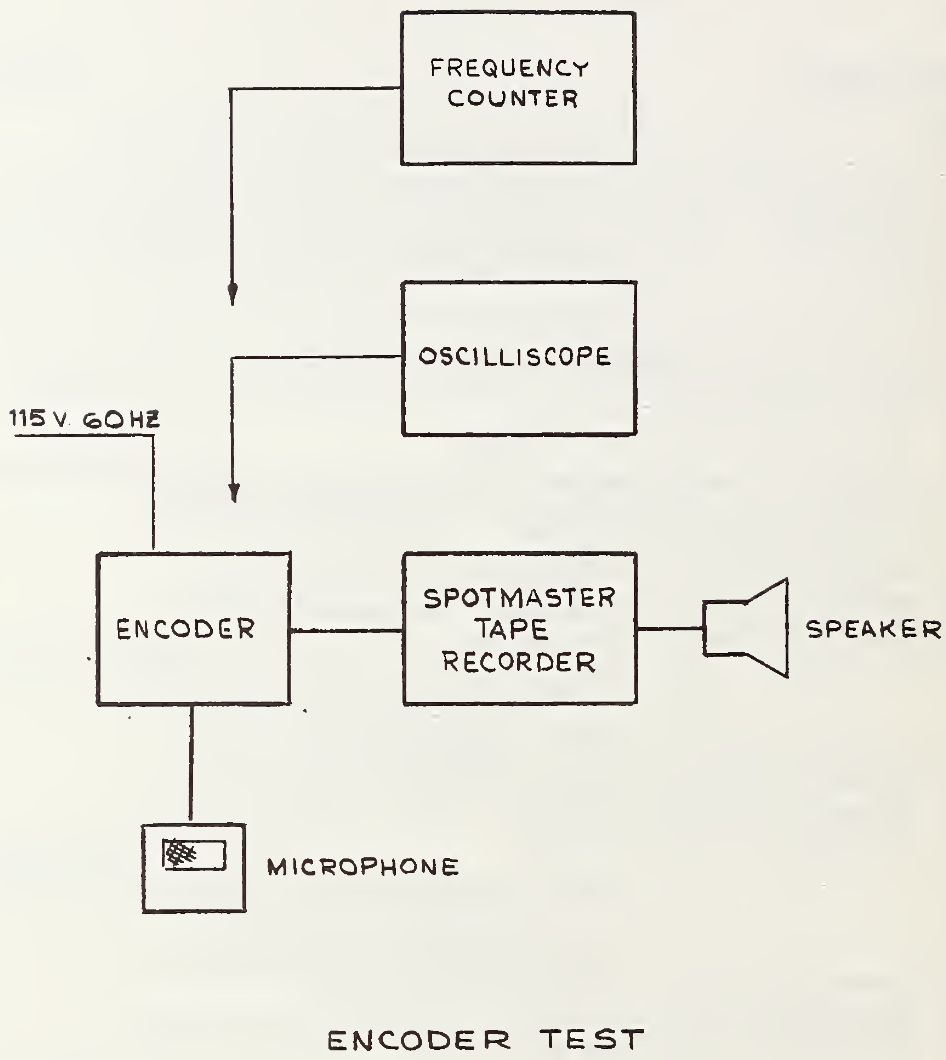


Figure 42. Encoder Test Setup.

TEST 2

CODE FORMAT

Requirement

The Encoder shall generate a code at its output designed to program the special-purpose HAIR unit. This code shall be constructed of alternate tones with a dead time between each tone burst.

The following codes shall be generated at the output of the Encoder:

FUNCTION	CODE
Channel 1	0 0 1 1
Channel 2	0 1 1 0
Trip Advisory	1 0 0 1
Trip Information	1 1 0 0
Fixed Emergency	0 0 0 0
End of Message	1 1 1 1
Emergency	1 0 1 0 (repeating)

Procedure

1. Interconnect the equipment as shown in Figure 42.
2. Turn on all equipment.
3. Remove the top of the Encoder.
4. Connect the storage oscilloscope to the audio output terminals located on the barrier strip inside the Encoder on the left side. Note: The terminals are marked "AUDIO OUTPUT."
5. Adjust the horizontal sweep speed on the oscilloscope to display 200 milliseconds per division on the screen.
6. Adjust the zero voltage point on the centerline of the vertical scale and the vertical amplifier gain to display 500 millivolts per division.
7. Depress the storage button on the oscilloscope.
8. Depress the single sweep button on the oscilloscope.
9. Depress the reset button on the oscilloscope.
10. On the Encoder selector switches, depress the Channel 1 Code button and the Initiate button. Make the following observations from the pattern on the screen of the oscilloscope:

a. The dual-tone burst is present at the start of the message.

Tone Burst____X____OK

Length of Burst____440____msec

b. The proper message follows.

Correct Message (0011)____X____OK

Bit Length____170____msec

Quiet Period Length____120____msec

11. Depress the reset button on the oscilloscope.

12. On the Encoder, depress the End of Message and Initiate buttons. Make the following observations from the pattern on the screen of the oscilloscope:

    a. The dual-tone burst is present at the start of the message.

    Tone Burst____X____OK

    Length of Burst____530____msec

    b. The proper code follows.

    Correct Message (1111)____X____OK

    Bit Length____170____msec

    Quiet Period Length____120____msec

13. Repeat Steps 9 and 10 for each of the required codes. At the completion of each test, depress the End of Message and Initiate buttons on the Encoder and then repeat Steps 9 and 10.

    Channel 2 Tone Burst____X____OK

    Length of Burst____440____msec

    Correct Message (0110)____X____OK

    Bit Length____170____msec

    Quiet Period Length____120____msec

Trip Advisory Tone Burst______X______OK

Length of Burst______440______msec

Correct Message (1001)______X______OK

Bit Length______170______msec

Quiet Period Length______120______msec

Trip Information Tone Burst______X______OK

Length of Burst______440______msec

Correct Message (1100)______X______OK

Bit Length______170______msec

Quiet Period Length______120______msec

Fixed Emergency Tone Burst______X______OK

Length of Burst______440______msec

Correct Message (0000)______X______OK

Bit Length______170______msec

Quiet Period Length______120______msec

14. Adjust the horizontal sweep to display one (1) second per division on the screen of the oscilloscope.
15. Depress the reset button on the oscilloscope.
16. On the Encoder, depress the Emergency and Enter buttons. Make the following observations:

    a. A dual-tone burst is present at the start of the message.

    Tone Burst______X______OK

    b. A repeating series of alternate tones follows.

    Message Correct (1010)______X______OK

    c. After eleven (11) alternating tone bits, observe a dual-tone burst.

    11 tone bits______X______OK

    Dual tone burst______X______OK

d. After the dual-tone burst, observe the End of Message Code.

End of Message (1111) ____X____ OK

e. The dual-tone burst is followed by the alternating tone bits.

NOTE: Statement should read: Cycle repeats after 1111 X OK

NOTE: This pattern of coding repeats itself automatically.

17. Change the horizontal sweep speed on the oscilloscope to display 400 msec per division and depress the reset button on the oscilloscope. Make the following observations:

a. The tones are alternating. Note: The End of Message and the dual-tone burst will also appear. The alternating tone will be displayed over approximately 5 divisions on the screen.

Alternating Tone ____X____ OK

18. Change the horizontal sweep speed to 200 msec per division on the oscilloscope and depress the reset button on the oscilloscope. Observe that the tones are alternating.

Alternating Tone ____X____ OK

Bit Length ____160____ msec

Quiet Period Length ____120____ msec

19. Depress the End of Message and Initiate buttons. Depress the reset button on the oscilloscope and observe that the Emergency Message stops.

____X____ OK

TEST 3

TAPE RECORDER CONTROL AND DRIVE

Requirement

The Encoder shall be capable of controlling the tape recorder's start-stop operating function in (1) automatic control by the Initiate button, (2) Manual control by the switch on the microphone. The Encoder shall have enough audio drive power to produce an input signal to the recorder of -5 dBm.

Procedure

1. Interconnect the equipment as shown in Figure 42.
2. Turn on all equipment.
3. Connect an 8-ohm 2-watt resistor to the audio output from the recorder.
4. Connect the oscilloscope across the 8-ohm resistor.
5. Talk into the microphone and adjust the Encoder gain control to achieve 15 dB of compression.
6. Adjust the recorder gain to achieve -5 dBm record level.
7. Depress the Channel 1 and Initiate buttons on the Encoder. Observe that the tape recorder starts automatically and then stops.

   X ______ OK

8. Activate the switch on the microphone. Observe that the tape recorder starts.

   X ______ OK

9. Record a short voice message on the tape explaining which code message was recorded. Example: This is a test recording of the Channel 1 select code.
10. On the Encoder, depress the End of Message and Initiate buttons.
11. Manually advance the tape format 5 seconds.
12. Repeat Steps 7 through 11 for each of the codes.

Channel 2 tape starts and stops X ______ OK

Manual start X ______ OK

Trip Advisory starts and stops ____X____OK

Manual start ____________________X____OK

Trip Information starts and stops ____X____OK

Manual start ____________________X____OK

Fixed Emergency starts and stops ____X____OK

Manual start ____________________X____OK

13. On the Encoder, depress the Emergency and Initiate buttons. Note: The recorder should start automatically and continue to run.

____________________________X____OK

14. Allow the emergency message to be recorded on the tape for 60 seconds.
15. Depress the End of Message and Initiate buttons on the Encoder.
16. Rewind the tape to the starting point.
17. Replay the recorded tape using the storage scope as it was adjusted in Test 2 Steps 5 through 9 to display the recorded information.
18. Record the following data:

NOTE: Unable to synchronize tape playback with storage scope. Basic information recorded previously. Section 18 omitted.

Channel 1 Dual-tone Burst ______________OK

Length of Burst ______________msec

Code Message ____/ / / / /____bits

Bit Length ______________msec

Quiet Period Length ______________msec

Channel 2 Dual-tone Burst ______________OK

Length of Burst ______________msec

Code Message ____/ / / / /____bits

Bit Length ______________msec

Quiet Period Length ______________msec

Trip Advisory Dual-tone Burst__________OK

Length of Burst________________msec

Code Message___/ / / / /_________bits

Bit Length_____________________msec

Quiet Period Length____________msec

Trip Information Dual-tone Burst______OK

Length of Burst________________msec

Code Message___/ / / / /_________bits

Bit Length_____________________msec

Quiet Period Length____________msec

Fixed Emergency Dual-tone Burst_______OK

Length of Burst________________msec

Code Message___/ / / / /_________bits

Bit Length_____________________msec

Quiet Period Length____________msec

End of Message Dual-tone Burst_________OK

Length of Burst________________msec

Code Message___/ / / / /_________bits

Bit Length_____________________msec

Quiet Period Length____________msec

19. Rewind the tape to the starting position.
20. Remove the 8-ohm resistor and connect a speaker to the output of the recorder.
21. Replay the tape and observe that the audio voice messages are of adequate amplitude and are clear without excessive background noise.

Voice Messages_________X_________OK

TEST 4

STORAGE AND LOW TEMPERATURE OPERATION

Requirement

The Encoder shall be capable of proper operation after being stored at temperature extremes of -40°F to +185°F. It shall also operate normally over the ambient temperature range of -20°F to +140°F.

Procedure

1. Interconnect the equipment as shown in Figure 42.
2. Place the Encoder in a controlled environment enclosure. Do not turn the Encoder on.
3. Adjust the controls on the enclosure to achieve an enclosure temperature of -40°F.
4. Allow the Encoder to soak at this temperature for two (2) hours.
5. Adjust the enclosure temperature control to achieve an enclosure temperature of -20°F.
6. Allow the Encoder to stabilize at this temperature for at least 30 minutes.
7. Turn on all equipment.
8. Repeat Test 3 and record the data.
9. Turn off all equipment.
10. Adjust the enclosure controls to achieve an enclosure temperature of +185°F.
11. Allow the Encoder to soak at this temperature for two (2) hours.
12. Adjust the enclosure temperature controls to achieve an enclosure temperature of +140°F.
13. Allow the Encoder to stabilize at this temperature for at least 30 minutes.
14. Turn on all equipment.
15. Repeat Test 3 and record the data.

Note: It was practically impossible to perform Test 3 with the encoder inside the oven. As a substitute for Test 3, the following test was performed: with the EMER message button depressed, the encoder was placed in the oven with the cables outside. The power plug was left disconnected until tests were made. Test consisted of: (1) observing EMER cycle and (2) measuring subaudible tone.

		140°F	-20°F		140°F	-20°F
Hot-Cold Tests of Encoder:	1. EMER Message	X OK	X OK	3. Pulse Length	90-100 ms	150 ms
	2. FREQ of SAT	82.5 Hz	82.4 Hz	4. Quiet Time	90 ms	120-130 ms

APPENDIX B

LABORATORY TEST PLAN

HIGHWAY ADVISORY RADIO

GENERAL

The objective of these tests is to measure the operating parameters of the Highway Advisory Information Radio (HAIR) unit. The results of these tests will provide important equipment data for the field tests. Further, these tests will establish the operating parameters, limits, and functional characteristics of this equipment.

APPROACH

Comprehensive controlled laboratory tests will be performed on the HAIR adapter unit. These tests will be conducted using calibrated measurement instruments in test equipment setups designed to measure specific identified parameters. These parameters are deemed important to the following field tests and their evaluation:

A. Equipment Required:

2 ea. Hewlett-Packard 606A rf signal generator
1 ea. Hewlett-Packard 610 vacuum tube voltmeter
1 ea. AC millivolt meter, dB scale
1 ea. Frequency counter
1 ea. Oscilloscope
1 ea. Controlled environment enclosure
1 ea. Volt-ohm meter
1 ea. Selective field strength meter
1 ea. Tektronix 7613 storage oscilloscope

SPECIAL PROCEDURE

Prior to initiating each test, assure that all equipment is properly interconnected, turned on, and allowed to warm up.

Special care must be taken to prevent ground currents or outside noise from being coupled into the test setup. Coaxial cabling, ground planes, and heavy ground wires should be used where necessary to eliminate noise.

The Storage Temperature Test (Test 17) is at the extreme temperature range; therefore, care must be exercised to ensure that the equipment has returned to normal operating range before operational tests are conducted. Connect a wire between Terminal #1 and ground on the receiver rf PC board.

TEST 1

INPUT CHANNEL AND FREQUENCY

Requirement

This receiver has two fixed-tuned channels selected by either an external code signal or a manual pushbutton, one at 1606 kHz and the other at 530 kHz. The purpose of these tests is to determine that the receiver operates on both channels and on the correct frequencies.

Procedure

1. Interconnect the instruments in accordance with Figure 43.
2. Turn on and adjust the HP-606A rf signal generator to 530 kHz. Switch the signal generator for modulation by an external source. Set the rf output attenuator to deliver a 100 µV signal.
3. Turn on the Digital Encoder and depress the Emergency Code button and the Initiate button.
4. Adjust the modulation level to achieve a 30% level on the rf generator.
5. Depress the End of Message button.
6. Turn on the HAIR unit (auto radio) and depress the Roadside Message button on the HAIR selector switches.
7. On the Encoder, depress the Channel 1 Code button, the Initiate button, the End of Message button and the Initiate button.
8. Observe that the Channel 1 light on the HAIR unit (auto radio) is lit.
9. On the Encoder, depress the Roadside Message button and the Initiate button.
10. Adjust the audio oscillator to produce 400 Hz. Adjust the output amplitude and the Encoder input gain control to achieve 30% modulation on the rf signal generator.
11. Turn up the volume control on the HAIR unit (auto radio). There should be a 400 Hz tone coming from the HAIR unit speaker.
12. On the Encoder, depress the End of Message button and the Initiate button.
13. On the Encoder, depress the Channel 2 Code button, the Initiate button, and the End of Message button.
14. Observe that the Channel 2 light on the HAIR unit is lit.
15. Depress the Trip Advisory button on the HAIR unit selector switch.

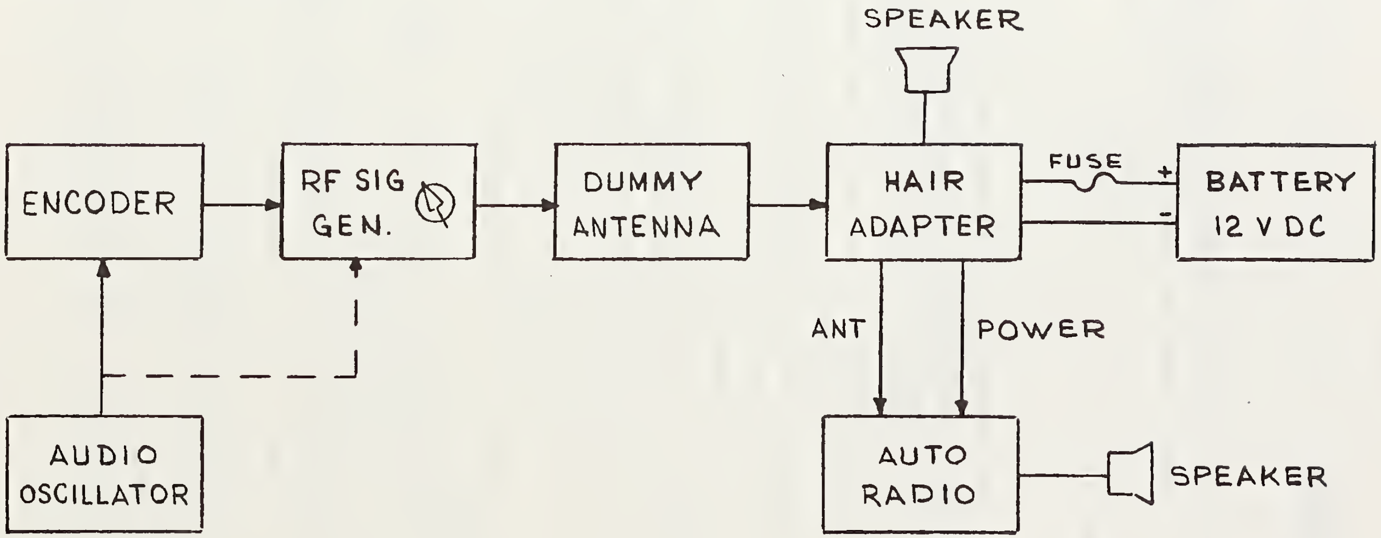


Figure 43. Equipment Setup.

16. On the Encoder, depress the Trip Advisory Code button and the Initiate button.
17. Adjust the rf signal generator to produce 1606 kHz output.
18. Observe that a 400 Hz tone is coming from the HAIR unit speaker.

Channel 1 ____X____ OK

Channel 2 ____X____ OK

TEST 2

ANTENNA CIRCUIT ISOLATION

Requirement

There shall be sufficient isolation built into the HAIR adapter to provide optimum operation of both the auto radio and the HAIR adapter on the same antenna.

Procedure

1. Interconnect the equipment as shown in Figure 44.
2. Adjust the rf signal generator to produce an output signal of 540 kHz with 400 Hz 30% modulation at an output amplitude of 300 μV.
3. Turn on the auto radio and increase the volume control. Tune the auto radio to receive the signal generator signal. Observe that a tone is coming from the auto radio speaker.
4. Adjust the signal generator output signal until a clear indication of signal amplitude is observed on the voltmeter.
5. Tune the receiver for a maximum indication on the voltmeter.
6. Record the output level from the signal generator.
7. Tune the signal generator to produce an output signal at 550 kHz.
8. Adjust the auto radio tuning to the new frequency and obtain a maximum indication on the voltmeter.
9. Adjust the rf signal generator output to obtain the same indication on the voltmeter as was achieved in Step 6.
10. Record the signal generator output level on the chart.
11. Repeat the above procedure every 50 kHz throughout the auto radio tuning range.
12. Reconnect the output from the dummy antenna directly into the auto radio.
13. Repeat the procedure outlined in Steps 3 through 11 and record the data.

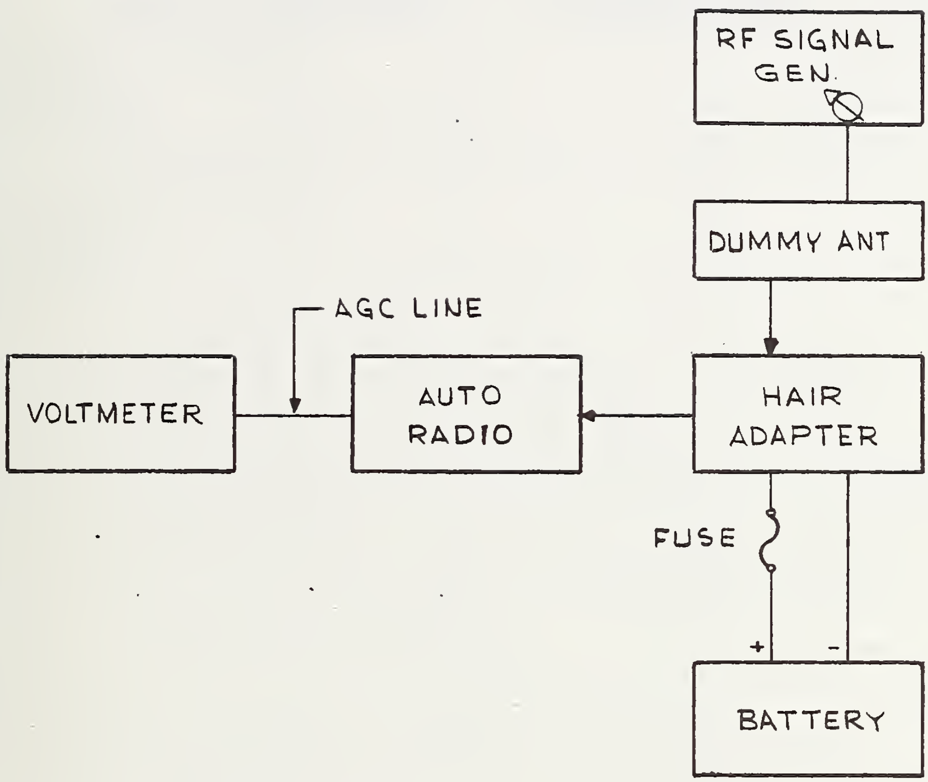


Figure 44. Antenna Isolation Test.

ANTENNA ISOLATION TEST DATA

Frequency (kHz)	Signal Generator Level Through HAIR Adapter	Signal Generator Level Directly Through Auto Radio
540	-85	-70
550	-77	-70
600	-70	-70
650	-69	-71
700	-69	-71
750	-68	-71
800	-68	-71
850	-67	-70
900	-67	-70
950	-66	-69
1000	-65	-69
1050	-65	-68
1100	-64	-68
1150	-64	-67
1200	-63	-67
1250	-63	-66
1300	-62	-66
1350	-61	-65
1400	-60	-64
1450	-59	-64
1500	-57	-63
1550	-55	-62
1600	-47	-63

AGC Level = 0.428 volt.

TEST 3

AUTO RADIO DISABLING

Requirement

When a message is being received by the HAIR unit, the auto radio will be disabled automatically.

Procedure

1. Interconnect the equipment as shown in Figure 43.
2. Turn on all equipment.
3. Follow the procedure outlined in Test 1, Steps 2 through 8.
4. Disconnect the antenna input to the auto radio and place a short length of wire on the antenna input.
5. Tune the auto radio until a local broadcast station is received and adjust the audio until normal listening is achieved from the auto radio speaker.
6. Follow the procedure outlined in Test 1, Steps 9 through 11.
7. The audio from the auto radio should stop and a 400 Hz tone should come from the HAIR unit.

   _________________X____________OK

8. Follow the procedure outlined in Test 1, Step 12.
9. The audio tone from the HAIR unit should stop and the auto radio should function.

   _________________X____________OK

TEST 4

ANTENNA PROTECTION

Requirement

The auto radio and HAIR unit shall not be damaged by static buildup and discharge from the antenna.

Procedure

1. Connect the equipment as shown in Figure 45 and turn on the HAIR unit and auto radio.
2. With the switch in Position 1, adjust the insulation test set to 5000 volts. Allow one minute for the capacitor to charge completely.
3. Move switch to Position 2. Repeat Steps 2 and 3 several times.
4. Disconnect the wire into the dummy antenna and connect the rf signal generator.
5. Follow the procedure outlined in Test 1, Steps 2 through 18.
6. Repeat the procedure outlined in Steps 1 through 4 for both channels of the HAIR unit.

Channel 1__________________________OK

Channel 2__________________________OK

Note: By mutual agreement between DOT and ARC, this test was not considered essential and has been omitted due to the risk of damage that can occur in the receiver.

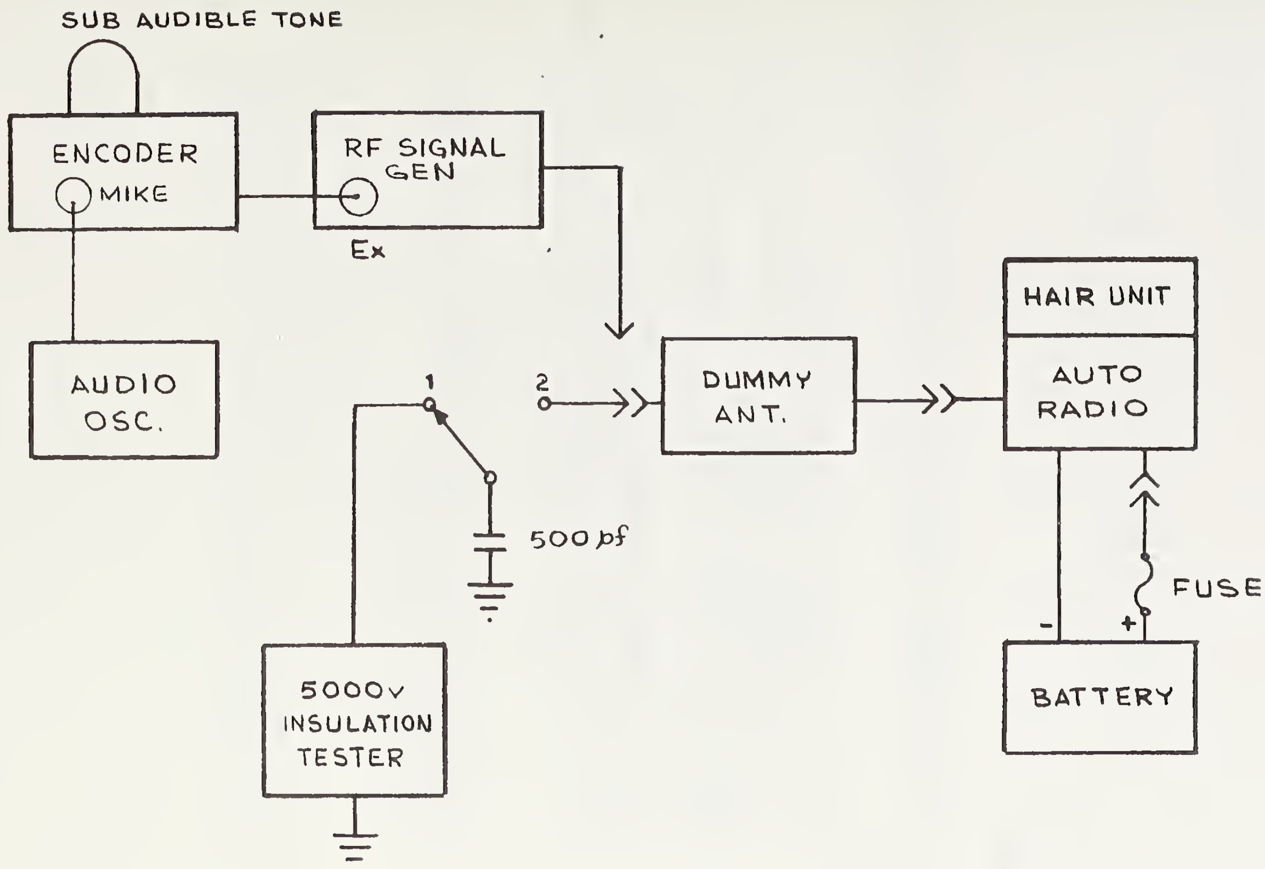


Figure 45. Antenna Protection Test.

Test 5

POWER SENSITIVITY

Requirement

The HAIR adapter receiver shall develop a minimum of 2 watts at the speaker for either channel with a 20 μV rf signal modulated 80% with 1000 Hz.

Procedure

1. Connect the equipment as shown in Figure 43.
2. Follow the procedure as outlined in Test 6 (Signal plus Noise-to-Noise Ratio), Steps 1 through 8.
3. Connect an oscilloscope across the 3.2 Ω speaker along with the voltmeter.
4. Adjust the audio volume control on the HAIR unit (auto radio) until sine wave limiting barely occurs.
5. Record the reading on the voltmeter and compute power being delivered.

   At 530 kHz Volts 1.8 3.2Ω

   Watts 1.01

6. Program the receiver to 1606 kHz with the Encoder and repeat the above test at this frequency.

   At 1.606 MHz Volts 2.1 3.2Ω

   Watts 1.37

TEST 6

SIGNAL-TO-NOISE RATIO

Requirement

The receiver shall have a signal plus noise-to-noise ratio of at least the following at laboratory ambient temperature levels:

rf Signal Level (μV)	20	50	1000	3000
(S+N)/N (dB)	16	26	34	34

Procedure

1. Connect the equipment as shown in Figure 43 and turn on all equipment. Turn down the volume control on the HAIR unit (auto radio).
2. Tune the signal generator to 530 kHz and adjust the output attenuator to deliver 20 μV into the dummy antenna.
3. Depress the Channel 1 selector switch on the HAIR unit.
4. Depress the Trip Advisory button on the HAIR selector switch.
5. On the Encoder, depress the Trip Advisory button and the Initiate button.
6. Switch the signal generator to internal 1000 Hz modulation and adjust to achieve 80% modulation.
7. Disconnect the speaker from the HAIR unit (auto radio) and replace it with a 4-ohm 2-watt carbon resistor.
8. Connect an rms voltmeter with a dB scale across the 4-ohm resistor.
9. Adjust the audio volume control on the HAIR unit (auto radio) to read at a reference dB level between 0.7 and 2.0 volts rms.
10. Record this reading as the 0 dB reference.
11. Adjust the modulation to zero percent.
12. Record the reading on the voltmeter (use the dB scale).
13. Repeat this procedure for the rf signal levels shown on the chart always adjusting to achieve 80% modulation for each rf signal level and then to zero (0) percent to measure the noise.

TEST DATA SHEET

SIGNAL + NOISE-TO-NOISE RATIO

Frequency (kHz)	Input Signal (μV)	S+N (dB)	N (dB)	Ratio (dB)
530	20	0	-21	
	50	0	-23	
	1000	0	-36	
	3000	0	-37	
1.606	20	0	-27	
	50	0	-32	
	1000	0	-38	
	3000	0	-38	

TEST 7

ADJACENT CHANNEL SELECTIVITY

Requirement

The HAIR unit shall have a minimum of 23 dB rejection to the adjacent standard broadcast channels.

Procedure

1. Interconnect the equipment as shown in Figure 46.
2. Turn on all equipment.
3. Depress the Channel 1 (530 kHz) channel select button on the HAIR unit.
4. Adjust rf signal generator #1 to produce an output signal at 530 kHz at a level of 200 μV.
5. Depress the Trip Advisory button on the HAIR selector switches.
6. On the Encoder, depress the Trip Advisory button and the Initiate button.
7. Adjust the audio oscillator to 1000 Hz frequency and its output to achieve 30% modulation on the rf signal generator.
8. Adjust the volume control on the HAIR unit (auto radio) to achieve 1-watt output (1 volt rms across the 4-Ohm resistor).
9. Remove the modulation from signal generator #1.
10. Adjust rf signal generator #2 to produce a signal at 540 kHz at an amplitude of 200 μV with 30% modulation of a 1000-Hz signal.
11. Measure the signal produced by signal generator #2 across the 4-ohm resistor and record the amplitude.

    For 300 to 3 kHz bandwidth
    Output Volts__with filter: 40 dB rejection
    without filter: 29 dB rejection
    Watts________________

12. Adjust the output of rf signal generator #2 to minimum.
13. On the Encoder, depress the End of Message button and the Initiate button.
14. Use the Encoder to program the HAIR unit to 1606 kHz.
15. Depress the Local Advisory button on the HAIR unit.
16. On the Encoder, depress the Local Advisory button and the Initiate button.

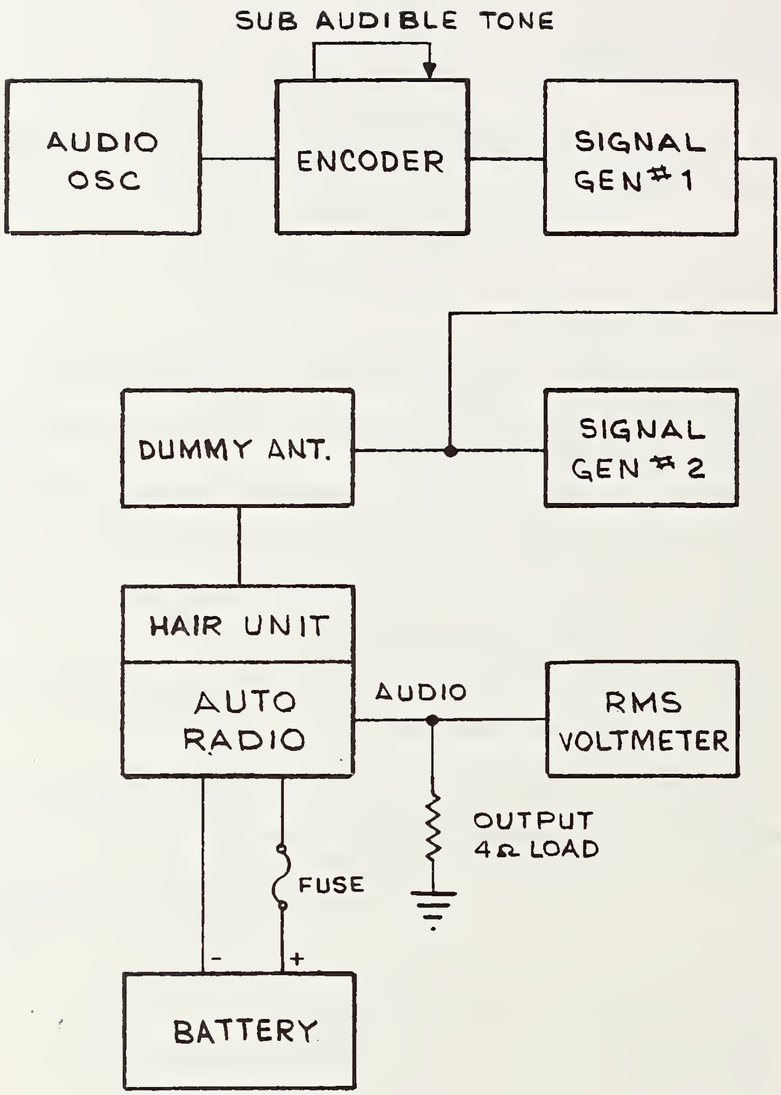


Figure 46. Adjacent Channel Test.

17. Repeat Steps 7 through 11 for the new channel using 1600 kHz as the adjacent channel.

Output Volts For 300 - 3 kHz bandwidth

Watts with filter: 26 dB rejection

Test 8

FAR CHANNEL SELECTIVITY

Requirement

The HAIR unit shall have a minimum of 46 dB rejection to a signal 40 kHz removed from the desired signal (530 kHz - 1606 kHz).

Procedure

1. Connect the equipment as shown in Figure 46.
2. Follow the procedure outlined in Test 7 for Adjacent Channel Selectivity except increase signal generator #2 output by 20 dB to 2000 µV and adjust its frequency 40 kHz away from the desired channel frequency; i.e., 570 kHz and 1566 kHz.

Channel 1 (530 kHz):

Output Volts 49 dB rejection

Watts Ref = 0 dB.

Channel 2 (1606 kHz):

Output Volts 49 dB rejection

Watts Ref = 0 dB

TEST 9

CHANNEL BANDWIDTH

Requirement

Each channel of the HAIR unit shall have a minimum over-all bandwidth of ± 3 kHz to the 3 dB point.

Procedure

1. Interconnect the equipment as shown in Figure 43.
2. Turn on all equipment.
3. Depress the Channel 1 (530 kHz) select button on the HAIR unit and the Roadside Message button. On the Encoder, depress the Roadside Message button and the Initiate button.
4. Connect the audio oscillator into the rf signal generator through the mixer pad and adjust the level to achieve 30% modulation with 1000 Hz.
5. Replace the speaker with a 4-ohm 2-watt resistor and connect an rms voltmeter across it. NOTE: Use a voltmeter with a dB scale.
6. Adjust the volume control on the HAIR unit (auto radio) to achieve a reference level on the voltmeter between 0.7 and 2 volts. NOTE: Set output at a convenient dB reference point.
7. Adjust the frequency of the audio oscillator down in frequency to the lowest frequency on the chart. Record the voltage reading on the voltmeter. NOTE: Be sure to maintain a constant percentage of modulation on the rf signal generator.
8. Adjust the frequency of the audio oscillator to the frequencies shown on the test chart and record the voltmeter reading at each frequency. NOTE: Record voltmeter readings in dB below the reference level.
9. Repeat the above procedure for 1606 kHz.

TEST DATA SHEET

CHANNEL BANDWIDTH

Audio Frequency (Hz)	Voltmeter Reading (dB)	
	530 kHz	1606 kHz
20	-7	-5.5
40	-2.5	-3.5
60	-5	+0.4
100	-3.5	0
150	-1.8	+2.0
200	-1.0	-0.2
400	0	+0.5
600	+0.3	+0.7
1000	0	+0.5
1500	0	0
2000	-0.3	-0.5
2500	-1.4	-1.2
3000	-3.6	-2.0
4000	-10	-4.0
5000	-15	-6

Reference 0 dB at 1650 kHz

Test 10

RF INTERMODULATION

Requirement

The intermodulation product produced by two out-of-channel signals of an amplitude not less than 5 mV and spaced in frequency such that $f_1 + 2f_2 = f_0$ (desired channel frequency) shall be at least 20 dB below one-watt output.

Procedure

1. Interconnect the equipment as shown in Figure 46.
2. Turn on the HAIR unit and all other equipment.
3. By using signal generator #1 and the procedure outlined in Test 7 (Adjacent Channel Selectivity) Steps 3 through 8, program the HAIR unit to Channel 1 (530 kHz).
4. Readjust signal generator #1 to 120 kHz and set the modulation at 50% and 400 Hz.
5. Adjust signal generator #2 to 205 kHz and set the modulation to 50% and 400 Hz.
6. Set each signal generator to produce an output of 5000 µV at the input to the dummy antenna.
7. Without adjusting the gain on the receiver, measure the output voltage developed across the 4-ohm resistor. NOTE: Make sure the two signal generators are exactly on frequency.

Channel 1 (530 kHz):

Reference = 1 watt
= 2.0 volts

Volts 0.18

Watts 0.0081

8. If the output is below 10 mW (20 mV), adjust the signal generator output signals until 20 mV is achieved. Record the amplitude of the signal being delivered by both generators.

Generator 1 100 mv

Generator 2 100 mv

9. Repeat the above measurement for Channel 2 (1606 kHz) using the Encoder to program the receiver to the new channel and setting the signal generator to 750 kHz and 428 kHz.

Channel 2 (1606 kHz):

Reference = 1 watt	Volts 0.35[1]
= 2.0 volts	Watts 0.0306
	Generator 1 100 mv[2]
	Generator 2 100 mv

---

[1]Noise level without the 1.606 kHz signal percent

[2]100 mv level is required from each generator to produce a significant change in audio output.

TEST 11

AGC SENSITIVITY

Requirement

Determine the change in the output audio signal as the input rf signal is varied.

Procedure

1. Interconnect the equipment as shown in Figure 43.
2. Turn on all equipment.
3. By using the procedure outlined in Test 1, Steps 2 through 11, program the HAIR unit (auto radio) to Channel 1 (530 kHz).
4. Disconnect the speaker and connect a 4-ohm 2-watt resistor in its place.
5. Connect an rms voltmeter across the 4-ohm resistor.
6. Adjust the audio volume control to achieve a reference output between 0.5 and 1.0 volt rms.
7. Adjust the signal generator output rf attenuator to minimum. Record the reading on the voltmeter.
8. Adjust the rf output attenuator to develop each of the voltage steps shown on the attached chart. Record the data, as required.
9. Repeat the above measurements for Channel 2 (1606 kHz).

TEST DATA SHEET

AGC SENSITIVITY

Input Signal (μV)	Output Signal Amplitude (dB)	
	Channel 1 (volt)	Channel 2 (volt)
0	0.13 (noise)	0.25
1	0.13	0.33
3	0.14	0.66
10	0.19	0.82
30	0.45	0.87
100	1.00	0.92
300	1.30	0.95
1k	1.45	0.96
3k	1.60	0.99
10k	1.90	2.05

TEST 12

OVERLOAD

Requirement

To determine the maximum signal overload point of the HAIR unit.

Procedure

1. Interconnect the equipment as shown in Figure 43.
2. Turn on all equipment.
3. By using the procedure outlined in Test 1, Steps 2 through 9, program the HAIR unit to Channel 1 (530 kHz).
4. Disconnect the speaker and connect a 4-ohm 2-watt resistor.
5. Switch the signal generator modulation switch to internal 1000 Hz and adjust the amplitude to produce 30% modulation.
6. Adjust the audio volume control to produce 2 volts rms across the 4-ohm resistor.
7. Adjust the audio distortion analyzer to measure the distortion on the output audio signal.
8. Insrease the rf signal generator output signal until 15% audio distortion is observed. NOTE: Adjust the audio volume control to maintain a constant 2-volt output signal.

   rf Signal Amplitude ____100 mv____

9. Repeat the above tests for Channel 2 (1606 kHz).

   rf Signal Amplitude ____20 mv____

TEST 13

AGC TIME CONSTANT

Requirement

The audio output signal amplitude shall recover to within 2 dB of its initial value within 0.3 second when a ± 10 dB step change occurs in the rf input signal.

Procedure

1. Interconnect the equipment as shown in Figure 43.
2. Turn on all equipment.
3. By using the procedure outlined in Test 1, Steps 2 through 9, program the HAIR unit (auto radio) to Channel 1 (530 kHz).
4. Disconnect the speaker on the HAIR unit and connect a 4-ohm resistor in its place.
5. Switch the signal generator modulation switch to internal and 1000 Hz modulation. Adjust the modulation amplitude to 30%.
6. Adjust the oscilloscope to display 50 milliseconds per division on the horizontal scale and 1.0 volt per division on the vertical scale.
7. Adjust the oscilloscope vertical zero at the bottom index line on the screen and the vertical gain to achieve a 2 division indication.
8. Set the trigger to cause the sweep when a positive-going signal appears.
9. Adjust the trigger point until the residual signal into the oscilloscope does not cause a trace.
10. Step the rf signal attenuator to achieve a 10 dB step increase in input signal.
11. Measure and record the time required for the output signal to recover to within +2 dB (2.5 division).
12. Repeat the measurement three (3) times and average the results.

    Time ____________50____________ msec

13. Repeat the above measurements for Channel 2 (1606 kHz).

    Time ____________50____________ msec

TEST 14

AUDIO

Requirement

The audio output amplifier shall be capable of withstanding a short (or open) circuit at its output without damage.

Procedure

1. Interconnect the equipment as shown in Figure 43.
2. Turn on all equipment.
3. By using the procedure outlined in Test 1, Steps 2 through 9, program the HAIR unit to receive Channel 1 (530 kHz).
4. Switch the modulation switch on the signal generator to 1000 Hz and adjust the modulation amplitude to achieve 30% modulation.
5. With the volume adjusted to normal audio listening level, disconnect the speaker on the HAIR unit and short out the speaker wires.
6. Observe that no heating of the audio amplifier (U-19) occurs after 30 minutes.

X ________ OK

7. Reconnect the speaker and observe that the audio circuit still operates.

X ________ OK

8. Disconnect the speaker on the HAIR unit and leave it open-circuited for 30 minutes.
9. Reconnect the speaker and observe that the audio circuit still operates.

X ________ OK

TEST 15

DISTORTION

Requirement

The over-all audio output distortion shall be measured throughout the audio range 300 Hz to 3000 Hz.

Procedure

1. Interconnect the equipment as shown in Figure 43.
2. Turn on all equipment.
3. By using the procedure outlined in Test 1, Steps 2 through 9, program the HAIR unit to receive Channel 2 (1606 kHz).
4. Disconnect the speaker on the HAIR unit and connect a 4-ohm 2-watt resistor in its place.
5. Connect an audio frequency distortion analyzer across the 4-ohm resistor.
6. Disconnect the Encoder from the external modulation jack and connect the audio oscillator directly into the rf generator. Adjust the audio frequency to 1000 Hz with an amplitude sufficient to produce 65% modulation.
7. Adjust the audio volume control to produce 2.0 volts rms (1.5 watts) across the 4-ohm resistor.
8. Adjust the frequency of the audio oscillator to 300 Hz.
9. Readjust the amplitude to maintain 1.0 watts output and 30% modulation.
10. Adjust the audio distortion analyzer to determine the percentage of distortion.
11. Repeat the above measurements for each frequency shown on the chart.

TEST DATA SHEET

AUDIO DISTORTION MEASUREMENTS

Audio Frequency (Hz)	Distortion (%)
300	5.8
400	4.8
600	4.0
1000	3.6
1500	3.2
2000	3.0
2500	3.0
3000	3.0

TEST 16

CHANNEL SELECT FUNCTION

Requirement

This test is to determine whether the Decoder section of the HAIR unit can program the receiver section to the two channels either manually or by a signal transmitted into the receiver.

Procedure

The automatic channel select sequence has already been tested in Test 1 (Input Channel and Frequency). This procedure outlines the test to determine proper operation of the manual selection.

1. Interconnect the equipment as shown in Figure 43.
2. Turn on all equipment.
3. Manually select Channel 1 and Trip Advisory on the HAIR (Auto Radio) selector switches.
4. Tune the rf signal generator to 530 kHz.
5. Switch the generator modulation switch to external modulation.
6. On the Encoder, depress the Trip Advisory and Initiate selector switches.
7. Adjust the audio oscillator to produce 400 Hz at 30% modulation on the rf signal generator
8. Adjust the volume control on the HAIR (Auto Radio) until normal listening level is obtained.
9. Observe that the Channel 1 light is lit.
10. Depress the Channel 2 selector switch on the HAIR (Auto Radio) unit.
11. Observe that the Channel 2 light is lit.
12. Adjust the rf signal generator to 1606 kHz and observe that the 400 Hz tone is coming from the HAIR (Auto Radio) unit speaker.

Manual Channel Select #1 ____X____

Manual Channel Select #2 ____X____

TEST 17

DECODER PRIORITY CODE

Requirement

The Decoder shall have a priority select switch system which shall provide selection of three levels of message priority: (1) emergency, (2) Trip Advisory, (3) Trip Information. Further, the priority selector switch on the HAIR unit will lock out all lower priority messages other than the one selected. The Decoder also will prevent any message except fixed and mobile emergency from being received more than once.

Procedure

1. Interconnect the equipment as shown in Figure 43.
2. Turn on all equipment.
3. Depress the Channel 1 selector switch (530 kHz) on the HAIR (Auto Radio) unit.
4. Adjust the rf signal generator to 530 kHz and switch the modulation switch to modulate the generator by an external source.
5. Depress the emergency button on the HAIR (Auto Radio) unit selector switch.
6. On the Encoder, depress the Trip Advisory and Initiate buttons.
7. Adjust the audio oscillator to produce 30% modulation on the rf signal generator.
8. Increase the volume on the HAIR (Auto Radio) unit and observe that no tone is coming from the HAIR unit speaker.

    ______________________X__________OK

9. Depress the Trip Advisory button on the HAIR (Auto Radio) selector switch. Observe that the 400 Hz tone is coming from the HAIR unit speaker.

    ______________________X__________OK

10. On the Encoder, depress the End of Message button and the Initiate button.
11. Observe that the HAIR adapter has been disabled and the auto radio is now functioning.
12. On the Encoder, depress the Trip Advisory and Initiate buttons.
13. Observe that the auto radio is still functioning and that the HAIR unit has ignored the second Trip Advisory message.

    ______________________X__________OK

14. On the Encoder, depress the End of Message and Initiate buttons.

15. Repeat Steps 5 through 9, except in Step 6, depress the Trip Information and the Initiate buttons on the Encoder.

16. Observe that in Step 9 the HAIR (Auto Radio) unit still does not operate.

_____________________X___________OK

17. Depress the Trip Information button on the HAIR (Auto Radio) unit. Observe that the 400 Hz tone is coming from the HAIR unit speaker.

_____________________X___________OK

18. Repeat Steps 10 through 14, except in Step 12, depress the Trip Information and the Initiate buttons.

19. HAIR unit ignored second Trip Information message.

_____________________X___________OK

20. Depress the fixed emergency and the Initiate buttons on the Encoder. Observe that the 400 Hz tone is coming from the HAIR (Auto Radis) unit even though the Trip Information selector switch is depressed on the HAIR unit.

_____________________X___________OK

21. Depress the Trip Advisory selector switch on the HAIR (Auto Radio) unit. Observe that the emergency signal is still coming from the HAIR unit speaker.

_____________________X___________OK

TEST 18

EMERGENCY SIGNAL

Requirement

The HAIR (Auto Radio) unit shall produce an audible tone from the speaker and a flashing light when the emergency signal is being received.

Procedure

1. Interconnect the equipment as shown in Figure 43.
2. Turn on all equipment.
3. Manually select Channel 1 and Emergency on the HAIR (Auto Radio) unit selector switch.
4. Tune the rf signal generator to Channel 1 (530 kHz).
5. Switch the modulation switch on the signal generator to external modulation.
6. On the Encoder, depress the Emergency and Initiate buttons.
7. Observe that a pulsating tone is coming from the speaker and the emergency light is blinking.

   ______________________X__________OK

8. On the HAIR (Auto Radio) unit, depress the Trip Advisory and then the Trip Information buttons. Observe that the emergency signals are still present.

   Tone__________________X__________OK

   Light_________________X__________OK

TEST 19

OPERATING TEMPERATURE

Requirement

The HAIR unit shall operate satisfactorily over the ambient temperature range of -20°F to +140°F.

Procedure

1. Place the HAIR adapter unit in a controlled environment enclosure.
2. Adjust the enclosure temperature control to achieve an enclosure temperature of -20°F.
3. Allow the HAIR unit to stabilize at this temperature for at least 30 minutes.
4. Conduct each of the following tests and record the results on the data sheets.

Test 1	Test 9
Test 3	Test 10
Test 6	Test 14
Test 7	Test 15

5. Adjust the enclosure temperature control to achieve an enclosure temperature of +140°F.
6. Allow the HAIR unit to stabilize at this temperature for at least 30 minutes.
7. Conduct each of the following tests and record the results on the data sheets.

Test 1	Test 9
Test 3	Test 10
Test 6	Test 14
Test 7	Test 15

TEST 19-1

INPUT CHANNEL AND FREQUENCY

Requirement

This receiver has two fixed-tuned channels selected by either an external code signal or a manual pushbutton, one at 1606 kHz and the other at 530 kHz. The purpose of these tests is to determine that the receiver operates on both channels and on the correct frequencies.

Procedure

1. Interconnect the instruments in accordance with Figure 43.
2. Turn on and adjust the HP-606A rf signal generator to 530 kHz. Switch the signal generator for modulation by an external source. Set the rf output attenuator to deliver a 100 μV signal.
3. Turn on the Digital Encoder and depress the Emergency Code button and the Initiate button.
4. Adjust the modulation level to achieve a 30% level on the rf generator.
5. Depress the End of Message button.
6. Turn on the HAIR unit (auto radio) and depress the Roadside Message button on the HAIR selector switches.
7. On the Encoder, depress the Channel 1 Code button, the Initiate button, the End of Message button and the Initiate button.
8. Observe that the Channel 1 light on the HAIR unit (auto radio) is lit.
9. On the Encoder, depress the Roadside Message button and the Initiate button.
10. Adjust the audio oscillator to produce 400 Hz. Adjust the output amplitude and the Encoder input gain control to achieve 30% modulation on the rf signal generator.
11. Turn up the volume control on the HAIR unit (auto radio). There should be a 400 Hz tone coming from the HAIR unit speaker.
12. On the Encoder, depress the End of Message button and the Initiate button.
13. On the Encoder, depress the Channel 2 Code button, the Initiate button, and the End of Message button.
14. Observe that the Channel 2 light on the HAIR unit is lit.
15. Depress the Trip Advisory button on the HAIR unit selector switch.

16. On the Encoder, depress the Trip Advisory Code button and the Initiate button.
17. Adjust the rf signal generator to produce 1606 kHz output.
18. Observe that a 400 Hz tone is coming from the HAIR unit speaker.

	Cold (-20°F)	Hot (140°F)	
Channel 1	X	X	OK
Channel 2	X	X	OK
	(Note 1)	(Note 2)	

Note 1: During the cold tests, it was discovered that the audio became noisy and the sensitivity at 530 kHz was decreased. It was determined that these problems were due to moisture. Subsequently the board was sprayed with antifungus coating.

Note 2: During hot tests, the sensitivity at 530 kHz was degraded and a 1 mυ signal was required for the capture of control pulses. Subsequent to the test, the 530 kHz channel will be realigned and tuned.

TEST 19-3

AUTO RADIO DISABLING

Requirement

When a message is being received by the HAIR unit, the auto radio will be disabled automatically.

Procedure

1. Interconnect the equipment as shown in Figure 43.
2. Turn on all equipment.
3. Follow the procedure outlined in Test 1, Steps 2 through 8.
4. Disconnect the antenna input to the auto radio and place a short length of wire on the antenna input.
5. Tune the auto radio until a local broadcast station is received and adjust the audio until normal listening is achieved from the auto radio speaker.
6. Follow the procedure outlined in Test 1, Steps 9 through 11.
7. The audio from the auto radio should stop and a 400 Hz tone should come from the HAIR unit.

Cold X OK	Hot X OK

8. Follow the procedure outlined in Test 1, Step 12.
9. The audio tone from the HAIR unit should stop and the auto radio should function.

Cold X OK	Hot X OK

TEST 19-6

SIGNAL-TO-NOISE RATIO

Requirement

The receiver shall have a signal plus noise-to-noise ratio of at least the following at laboratory ambient temperature levels:

rf Signal Level (μV)	20	50	1000	3000
(S+N)/N (dB)	16	26	34	34

Procedure

1. Connect the equipment as shown in Figure 43 and turn on all equipment. Turn down the volume control on the HAIR unit (auto radio).
2. Tune the signal generator to 530 kHz and adjust the output attenuator to deliver 20 μV into the dummy antenna.
3. Depress the Channel 1 selector switch on the HAIR unit.
4. Depress the Trip Advisory button on the HAIR selector switch.
5. On the Encoder, depress the Trip Advisory button and the Initiate button.
6. Switch the signal generator to internal 1000 Hz modulation and adjust to achieve 80% modulation.
7. Disconnect the speaker from the HAIR unit (auto radio) and replace it with a 4-ohm 2-watt carbon resistor.
8. Connect an rms voltmeter with a dB scale across the 4-ohm resistor.
9. Adjust the audio volume control on the HAIR unit (auto radio) to read at a reference dB level between 0.7 and 2.0 volts rms.
10. Record this reading as the 0 dB reference.
11. Adjust the modulation to zero percent.
12. Record the reading on the voltmeter (use the dB scale).
13. Repeat this procedure for the rf signal levels shown on the chart always adjusting to achieve 80% modulation for each rf signal level and then to zero (0) percent to measure the noise.

SIGNAL + NOISE-TO-NOISE RATIO

Frequency (kHz) Test Temperature	Input Signal (μV)	S+N (dB)	N (dB)	Ratio (dB)
	20	0	-13.5	+13.5
530	50	0	-25.0	25.0
Hot	1000	0	-28.0	28.0
140°F	3000	0	-30.5	30.5
	20	0	-25.5	+25.5
530	50	0	-30.5	30.5
Cold	1000	0	-39.0	39.0
-20°F	3000	0	-39.0	39.0
	20	0	-16.5	+16.5
1.606	50	0	-24.0	24.0
Hot	1000	0	-26.0	26.0
140°F	3000	0	-25.0	25.0
	20	0	-22.0	+22.0
1.606	50	0	-27.0	27.0
Cold	1000	0	-40.5	40.5
-20°F	3000	0	-41.0	41.0

ADJACENT CHANNEL SELECTIVITY

Requirement

The HAIR unit shall have a minimum of 23 dB rejection to the adjacent standard broadcast channels.

Procedure

1. Interconnect the equipment as shown in Figure 46.
2. Turn on all equipment.
3. Depress the Channel 1 (530 kHz) channel select button on the HAIR unit.
4. Adjust rf signal generator #1 to produce an output signal at 530 kHz at a level of 200 µV.
5. Depress the Trip Advisory button on the HAIR selector switches.
6. On the Encoder, depress the Trip Advisory button and the Initiate button.
7. Adjust the audio oscillator to 1000 Hz frequency and its output to achieve 30% modulation on the rf signal generator.
8. Adjust the volume control on the HAIR unit (auto radio) to achieve 1-watt output (1 volt rms across the 4-Ohm resistor).
9. Remove the modulation from signal generator #1.
10. Adjust rf signal generator #2 to produce a signal at 540 kHz at an amplitude of 200 µV with 30% modulation of a 1000-Hz signal.
11. Measure the signal produced by signal generator #2 across the 4-ohm resistor and record the amplitude.

    For 300 to 3 kHz bandwidth
    Output Volts with filter: 40 dB rejection
    without filter: 29 dB rejection
    Watts________________________________

12. Adjust the output of rf signal generator #2 to minimum.
13. On the Encoder, depress the End of Message button and the Initiate button.
14. Use the Encoder to program the HAIR unit to 1606 kHz.
15. Depress the Local Advisory button on the HAIR unit.
16. On the Encoder, depress the Local Advisory button and the Initiate button.

17. Repeat Steps 7 through 11 for the new channel using 1600 kHz as the adjacent channel.

		530 kHz			1.606 kHz	
Test Temperature	Output	No Filter	3 kHz Filter	Output	No Filter	3 kHz Filter
Hot 140°F	530 + 540	-2.5 dBm		530 + 540	0.5 dBm	-22.5 dBm
	540	-25.0 dBm		540	-8.0 dBm	-49 dBm
	Rejection[1]	-22.5 dB	Same	Rejection	-7.5 dB	-26.5 dB
Cold -20°F	530 + 540	10 dBm	10 dBm	530 + 540		0 dBm
	540	-25.0 dBm	-27.5 dBm	540		-14 dBm
	Rejection	-35 dB	-37.5 dB	Rejection		-14 dB[2]

[1] Loss of sensitivity causes noise level at -22.5 dB. Filter does not affect rejection. Increasing 540 kHz by 10 dB increases output only 2 dB.

[2] Low rejection is due to wide BW of RF and IF to be retuned.

TEST 19-9

CHANNEL BANDWIDTH

Requirement

Each channel of the HAIR unit shall have a minimum over-all bandwidth of ± 3 kHz to the 3 dB point.

Procedure

1. Interconnect the equipment as shown in Figure 43.
2. Turn on all equipment.
3. Depress the Channel 1 (530 kHz) select button on the HAIR unit and the Roadside Message button. On the Encoder, depress the Roadside Message button and the Initiate button.
4. Connect the audio oscillator into the rf signal generator through the mixer pad and adjust the level to achieve 30% modulation with 1000 Hz.
5. Replace the speaker with a 4-ohm 2-watt resistor and connect an rms voltmeter across it. NOTE: Use a voltmeter with a dB scale.
6. Adjust the volume control on the HAIR unit (auto radio) to achieve a reference level on the voltmeter between 0.7 and 2 volts. NOTE: Set output at a convenient dB reference point.
7. Adjust the frequency of the audio oscillator down in frequency to the lowest frequency on the chart. Record the voltage reading on the voltmeter. NOTE: Be sure to maintain a constant percentage of modulation on the rf signal generator.
8. Adjust the frequency of the audio oscillator to the frequencies shown on the test chart and record the voltmeter reading at each frequency. NOTE: Record voltmeter readings in dB below the reference level.
9. Repeat the above procedure for 1606 kHz.

CHANNEL BANDWIDTH

Audio Frequency (Hz)	Voltmeter Reading[1] Hot (530 kHz)	Cold (530 kHz)	Hot (1606 kHz)	Cold (1606 kHz)
20	-14.7[2]		-15.6[2]	-35.6[2]
40	-9.5[2]	-21.6[2]	-6.3[2]	-20.0[2]
60	-9.1[2]	-11.0[2]	-5.2[2]	-12.0[2]
100	-6.0[2]	-0.9[2]	-4.9[2]	-1.1[2]
150	-3.9	0.4[2]	-2.9	0.0[2]
200	-3.5	-0.2[2]	-1.9	-0.4[2]
400	-1.6	-0.2	-0.1	-0.4
600	-0.6	-0.1	0.3	-0.2
1000	-0.1	0	0.3	-0.1
1500	(Ref) 0 dB	(Ref) 0 dB	(Ref) 0 dB	(Ref) 0 dB
2000	-0.6	-0.2	-0.4	0
2500	-1.6	-2.8	-0.7	-0.1
3000	-3.5	-6.3	-1.5	-0.2
4000	-7.9	-12.0	-3.5	-0.9
5000	-11.5	-13.9	-5.7	-2.3

[1] Distorted Waveform

[2] Readings are peak-peak of audio waveform on a scope.

Bandwidth after Retuning at Room Temperature-Peak-Peak on Scope

Audio Frequency (Hz)	530 kHz Volt	530 kHz dB	1606 kHz Volt	1606 kHz dB
20	0.2[2]	-29.5	0.2[2]	-29.5
40	0.8[2]	-17.5	2.0[2]	-9.5
60	2.4[2]	-7.9	5.5[2]	-0.7
100	2.1	-9.1	3.7[2]	-3.7
150	2.4	-7.9	3.9	-3.7
200	2.7	-6.9	4.3	-2.8
400	3.3	-5.2	5.2	-1.2
600	3.7	-4.2	5.6	-0.6
1000	4.3	-2.8	5.9	-0.1
1500	5.0	-1.6	6.0 (Ref)	0
2000	5.8	-0.2	5.9	-0.1
2500	6.0 (Ref)	0	5.6	-0.6
3000	5.5	-0.7	5.2	-1.2
4000	2.6	-7.3	4.2	-3.0
5000	0.6	-20.0	3.3	-5.2

TEST 19-10

RF INTERMODULATION

Requirement

The intermodulation product produced by two out-of-channel signals of an amplitude not less than 5 mV and spaced in frequency such that $f_1 + 2f_2 = f_o$ (desired channel frequency) shall be at least 20 dB below one-watt output.

Procedure

1. Intercønnect the equipment as shown in Figure 46.

2. Turn on the HAIR unit and all other equipment.

3. By using signal generator #1 and the procedure outlined in Test 7 (Adjacent Channel Selectivity) Steps 3 through 8, program[1] the HAIR unit to Channel 1 (530 kHz).

4. Readjust signal generator #1 to 120 kHz and set the modulation at 50% and 400 Hz.

5. Adjust signal generator #2 to 205 kHz and set the modulation to 50% and 400 Hz.

6. Set each signal generator to produce an output of 5000 μV at the input to the dummy antenna.

7. Without adjusting the gain on the receiver, measure the output voltage developed across the 4-ohm resistor. NOTE: Make sure the two signal generators are exactly on frequency.

Channel 1 (530 kHz):

	Hot	Cold
Volts	22 mν	25 mν[2]
Watts	0.121 mν	0.156 mν

8. If the output is below 10 mW (20 mV), adjust the signal generator output signals until 20 mV is achieved. Record the amplitude of the signal being delivered by both generators.

	Hot	Cold
Generator 1	5000 μv	5 mν
Generator 2	5000 μv	5 mν

---

[1]Ref = 1.5 volts rms, (0.56 watts) at + 5 dB.

[2]Voltage level in noise.

9. Repeat the above measurement for Channel 2 (1606 kHz) using the Encoder to program the receiver to the new channel and setting the signal generator to 750 kHz and 428 kHz.

Channel 2 (1606 kHz):

	Hot	Cold
Volts	22 mV	150 mV[1]
Watts	0.121 mw	5.62 mw
Generator 1	5 mV	5 mV
Generator 2	5 mV	5 mV

[1]Voltage level in noise.

AUDIO

Requirement

The audio output amplifier shall be capable of withstanding a short (or open) circuit at its output without damage.

Procedure

1. Interconnect the equipment as shown in Figure 43.

2. Turn on all equipment.

3. By using the procedure outlined in Test 1, Steps 2 through 9, program the HAIR unit to receive Channel 1 (530 kHz).

4. Switch the modulation switch on the signal generator to 1000 Hz and adjust the modulation amplitude to achieve 30% modulation.

5. With the volume adjusted to normal audio listening level, disconnect the speaker on the HAIR unit and short out the speaker wires.

6. Observe that no heating of the audio amplifier (U-19) occurs after 30 minutes.

Hot	Cold	
X	X	OK
X	X	OK

7. Reconnect the speaker and observe that the audio circuit still operates.

Hot	Cold	
X	X	OK
X	X	OK

8. Disconnect the speaker on the HAIR unit and leave it open-circuited for 30 minutes.

9. Reconnect the speaker and observe that the audio circuit still operates.

Hot	Cold	
X	X	OK
X	X	OK

TEST 19-15

DISTORTION

Requirement

The over-all audio output distortion shall be measured throughout the audio range 300 Hz to 3000 Hz.

Procedure

1. Interconnect the equipment as shown in Figure 43.
2. Turn on all equipment.
3. By using the procedure outlined in Test 1, Steps 2 through 9, program the HAIR unit to receive Channel 2 (1606 kHz).
4. Disconnect the speaker on the HAIR unit and connect a 4-ohm 2-watt resistor in its place.
5. Connect an audio frequency distortion analyzer across the 4-ohm resistor.
6. Disconnect the Encoder from the external modulation jack and connect the audio oscillator directly into the rf generator. Adjust the audio frequency to 1000 Hz with an amplitude sufficient to produce 65% modulation.
7. Adjust the audio volume control to produce 2.0 volts rms (1.5 watts) across the 4-ohm resistor.
8. Adjust the frequency of the audio oscillator to 300 Hz.
9. Readjust the amplitude to maintain 1.0 watts output and 30% modulation.
10. Adjust the audio distortion analyzer to determine the percentage of distortion.
11. Repeat the above measurements for each frequency shown on the chart.

AUDIO DISTORTION MEASUREMENTS

Audio Frequency (Hz)	Distortion in Percent	
	Hot	Cold
300	7.8	7.5
400	7.8	7.4
600	6.8	6.6
1000	6.3	6.4
1500	5.5	6.2
2000	6.0	6.2
2500	7.0	7.2
3000	7.9	7.0

Carrier Frequency = 530 kHz.

TEST 19-20

STORAGE TEMPERATURE

Requirement

The HAIR unit shall survive when stored in a nonoperating condition over the temperature range from -40 to 185°F

Procedure

1. Place the HAIR adapter unit in a controlled environment enclosure.

2. Adjust the enclosure temperature control to achieve an enclosure temperature of -40°F.

3. Allow the HAIR unit (nonoperating) to soak at this temperature for two (2) hours.

4. Readjust the temperature control to achieve an enclosure temperature of -20°F and allow 30 minutes to stabilize.

5. Turn on the HAIR unit and conduct Test 1 with a battery supply of 15V dc.

Channel 1	X	OK
Channel 2	X	OK

6. Adjust the enclosure temperature controls to achieve an enclosure temperature of 165°F.

7. Allow the HAIR unit (nonoperating) to soak at this temperature for two (2) hours.

8. Allow the enclosure temperature to decrease to 140°F, then turn on the HAIR unit and conduct Test 1 with a battery supply of 14V dc.

Channel 1	X	OK
Channel 2	X	OK

9. Repeat the above test for an enclosure temperature of 185°F. Allow enclosure temperature to drop to 160°F before turning on the HAIR unit.

Channel 1	X	OK
Channel 2	X	OK

APPENDIX C

FIELD TEST PLAN

HIGHWAY ADVISORY RADIO

FIELD TEST PLAN
HIGHWAY ADVISORY RADIO

1.0 GENERAL

The field tests are intended to test all elements of the system and to permit evaluation of system performance as well as compliance with specifications. These tests fall into two main categories:

1. Initial equipment tests under field conditions which may not involve a complete antenna array and may involve both transmitters.

2. System tests with the entire antenna array deployed and one transmitter or the other in use at a given time.

Category 1 tests will be conducted in Atlantic Research Corporation's rear parking lot and areas immediately adjacent to the parking lot. These tests will consist of both transmitter and receiver tests. Some portions of these tests will be conducted with system equipment not fully packaged in environmental enclosures and with vehicular receivers in static positions and external to the vehicles. During the period of these tests, initial decisions and adjustments regarding threshold sensitivity for the receivers will be made. The Category 1 tests will ensure that all system elements are functioning in accordance with specifications, and any difficulties encountered will be analyzed and corrected prior to starting Category 2 testing.

Category 2 tests will be conducted along a section of the Dulles Access Road between Centerville Road and Sully Road. These tests will be on one frequency at a time; i.e., either 530 kHz or 1606 kHz. These tests will include field measurements throughout the message zone to verify array performance at each frequency. Each type of receiver will be tested and thoroughly exercised under varying traffic conditions and at different vehicle speeds.

2.0 PRELIMINARY TRANSMITTER TESTS

Set up transmitter, matching network, and one whip antenna to radiate an unmodulated carrier on Channel 1 or 2. Connect a Variac on the power source

to the transmitter and provide a means for measuring the rms ac power voltage to the transmitter. Provide some means of measuring the transmitter output power, such as with a dc voltmeter on the B^+ of the final stage. Monitor the radiated field strength at some convenient distance with a tunable narrowband receiver which gives an indication of relative carrier amplitude. The antenna for the receiver may be a loop or a monopole. Provide a frequency counter for accurately measuring the carrier frequency. The counter may be connected to an antenna, to the transmitter, or coupled to the transmitter cable by any method that will not load the transmitter (see Figure 47).

After establishing a proper match, make the following measurements:

1. Vary the 60 Hz ac power supply voltage ± 10% and observe changes in radiated signal amplitude and frequency.

2. When transmitting Channel 1 (530 kHz), use the tunable receiver and look for any radiation of the 2nd harmonic (1060 kHz) or 3rd harmonic (1590 kHz). Measure strengths of these harmonics, if present, relative to the fundamental.

3. Monitor the carrier frequency for at least 30 minutes and look for any drift in frequency that may occur with temperature of the system. Temperature readings may be ambient levels, if changing.

4. At the same time with #3, monitor the amplitude of the field and look for any relative change. Observe any change resulting from the removal of the matching unit covers, for one matching unit only at each channel.

5. Measure the 3 dB bandwidth of the transmitting system. Use an audio generator to modulate the carrier and monitor the amplitude of the audio signal from the received field (spectrum analyzer, oscilloscope, or ac voltmeter on receiver output, etc.) Increase the modulating frequency and note the frequency at which the audio amplitude drops 3 dB. The 3 dB bandwidth is twice this frequency. Be sure the matching network and transmitter are properly tuned.

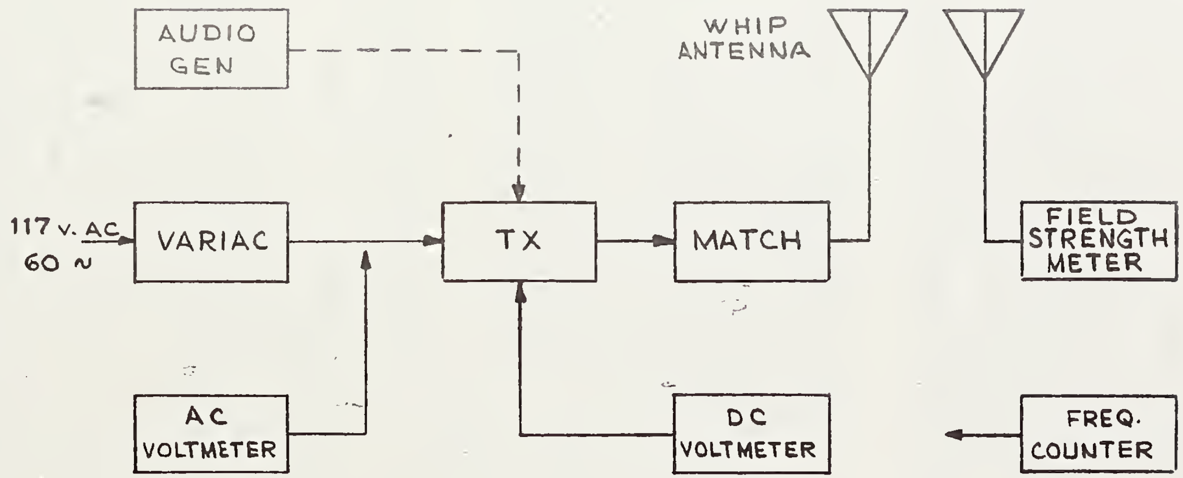


Figure 47. Equipment Setup for Preliminary Transmitter Tests.

6. Connect the three-way power divider to the transmitter. Operate one antenna from one port and terminate the other two in 50 ohms. Observe the drop in field strength relative to that without the power divider. Repeat for each port.

7. Use a calibrated receiver with a loop antenna and measure absolute field strength at 200 feet from the antenna. Record a measure of the transmitter power output. Do not use power divider. Measurements are to be made using each matching network for each channel. Measurements should be taken at different directions from the antenna for at least one of the matching networks on each channel.

NOTE: The use of a loop (H-field) antenna will provide accuracy within 3.5 dB if used no closer than 0.09λ to the test antenna. However, H-field data at closer ranges can be converted to E-field values using appropriate values of the intrinsic impedance shown in ARC report, "Fields of a Thin Vertical Antenna."

At 530 kHz, 0.09λ = 167 feet
At 1606 kHz, 0.09λ = 55 feet

DATE June 17, 1974

TIME 2:00 p.m.

WEATHER Clear

PERSONNEL JB/JD

DATA SHEET

2.1 Transmitter Operation On Each Channel

1.

AC Supply	Tx Ch. 1 Rel.Amp.	Tx Ch. 1 Freq.	Tx Ch. 2 Rel.Amp.	Tx Ch. 2 Freq.
105 Volts	3.06	530	2.95	1606
117 Volts	3.06	530	2.95	1606
129 Volts	3.06	530	2.95	1606

2. Tx Channel 1 only:

Frequency	Relative Amplitude		
Fundamental (530 kHz)	29.5 mV/m	-41.5 dB	-60.5 dB
2nd Harmonic (1060 kHz)	0.25 mV/m		
3rd Harmonic (1590 kHz)	27.5 μV/m	-19 dB	

3, 4.

Time	Temperature	Tx Ch. 1 Rel.Amp.	Tx Ch. 1 Freq.	Tx Ch. 2 Rel.Amp.	Tx Ch. 2 Freq.
0m	88°F	3.2	530	2.60	1606
5	88°F	3.2	530	2.60	1606
10	88°F	3.2	530	2.60	1606
15	88°F	3.2	530	2.60	1606
20	88°F	3.2	530	2.60	1606
25	88°F	3.2	530	2.60	1606
30	88°F	3.2	530	2.60	1606

	Rel.Amp., Ch. 1	Rel.Amp., Ch. 2
Matching Unit Cover On:	3.2	2.60
Matching Unit Cover Removed:	3.2	2.60
Matching Unit Serial No.	Unit 1	Unit 2

5.

Modulating Frequency	Rel.Amp., Ch. 1	Rel.Amp., Ch. 2
Min. (0 dB = 1.00)	2.12	1.40
Max. (-3 dB = 0.707)	1.5	0.98
Frequency	3200 Hz	3000 Hz
Matching Unit No.	Unit 2	Unit 2

| | BW = 2 X 3200 = 6.4 kHz | BW = 2 X 3000 = 6 kHz |

6.

	Power Divider			
	Input	Output #1	Output #2	Output #3
Channel 1	1.15W	2.3	2.3	2.3
Channel 2	1.25W	5.1	5.1	5.0

7.

Tx.	Match Unit	Tx Power Level (watts)	Field Strength (mV/m)	Azimuth
Channel 1	#1A	2.00	2.52	East
		2.00	2.60	West
		2.00	2.62	South
	#2A	2.00	2.51	East
	#3A	2.00	2.55	East
Channel 2	#1B	1.0	4.53	West
		1.0	4.50	East
		1.0	4.62	South
	#2B	1.0	4.55	East
	#3B	1.0	4.57	East

3.0 SYSTEM CODING TESTS

3.1 Channel Selection Tests

3.1.1 Set up two transmitting systems, one on each channel. Audio modulation is the combination of the subaudible tone (SAT) and the Encoder message (tone codes and voice). The Encoder message may be provided by the Encoder directly or by a prerecorded tape. As indicated in the test data sheets, the SAT is to be temporarily interrupted after completion of some of the messages to reset the lockout. Only one channel will be transmitting at a time and the modulating signal can be connected to either channel (see Figure 48).

Receive the signal on the test receivers. Observe that the correct channel light turns on and that the transmitted message is received on the correct channel. Channel switching is tested both manually and automatically. The tests include determining if the channel can be changed manually after being switched automatically.

The series of tests are to be made first on Channel 1 only, then repeated on Channel 2 only.

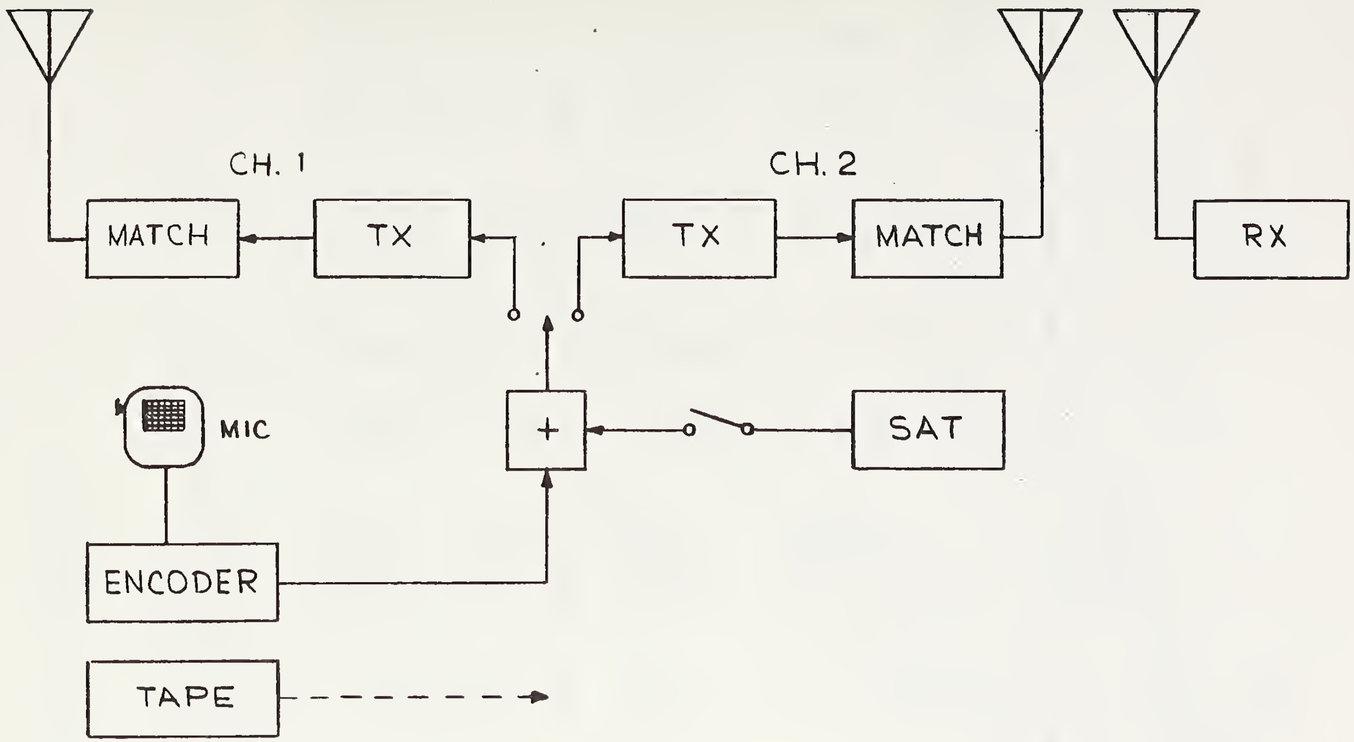


Figure 48. Equipment Setup for Channel Selection Tests.

DATE August 7, 1974

TIME 4:00 p.m.

WEATHER Clear

PERSONNEL JB/JD

DATA SHEET

3.1 Channel Selection Tests. The events in each column occur in time sequence in the order shown.

3.1.1

Transmit	Rx Press Button	Tx Message	Ch. Light #1	Ch. Light #2	Audio Received	Receiver OK #1	Receiver OK #2	Receiver OK #3
Ch. 1	Ch. 1	Trip Adv.	ON	OFF	YES	[X]	[X]	[ ]
	Ch. 2	Trip Adv.	OFF	ON	NO	[X]	[X]	[ ]
	Ch. 1	Trip Adv.	ON	OFF	YES	[X]	[X]	[ ]
	Ch. 1	Ch. 2	OFF	ON	---	[X]	[X]	[ ]
	---	Trip Adv.	OFF	ON	NO	[X]	[X]	[ ]
	Ch. 1	Trip Adv.	ON	OFF	YES	[X]	[X]	[ ]
Ch. 2	Ch. 1	Trip Adv.	ON	OFF	YES	[X]	[X]	[ ]
	Ch. 2	Trip Adv.	OFF	ON	NO	[X]	[X]	[ ]
	Ch. 1	Trip Adv.	ON	OFF	YES	[X]	[X]	[ ]
	Ch. 1	Ch. 2	OFF	ON	---	[X]	[X]	[ ]
	---	Trip Adv.	OFF	ON	NO	[X]	[X]	[ ]
	Ch. 1	Trip Adv.	ON	OFF	YES	[X]	[X]	[ ]

Note: Receiver #1 = Adapter Unit
Receiver #2 = Integrated Radio
Receiver #3 = Portable

Same identifiers for all data sheets.

3.1.2 Dual-Channel Operation

Set up both transmitting systems for simultaneous operation. Feed the SAT into both channels simultaneously through the adding networks. The Encoder can provide the message codes for one channel and the tape recorder for the other. The object of this test is to observe receiver operation while both channels are transmitting messages and commands to change the channel received. It will be necessary to interrupt SAT after each Trip Advisory message to remove interlock. Use the following format for the tape:

```
0s                 10s  14s       15s  20s                    29s  30s   (Repeat)
|TA - Voice A - EM |    |C1 - EM  |    |TA - Voice B - EM     |    |TA - Voice A - ...
|<----- SAT ------>|    |<-SAT--->|    |<------- SAT -------->|    |<----- SAT ---
```

where

TA = Trip Advisory Start Code

EM = End of Message Code

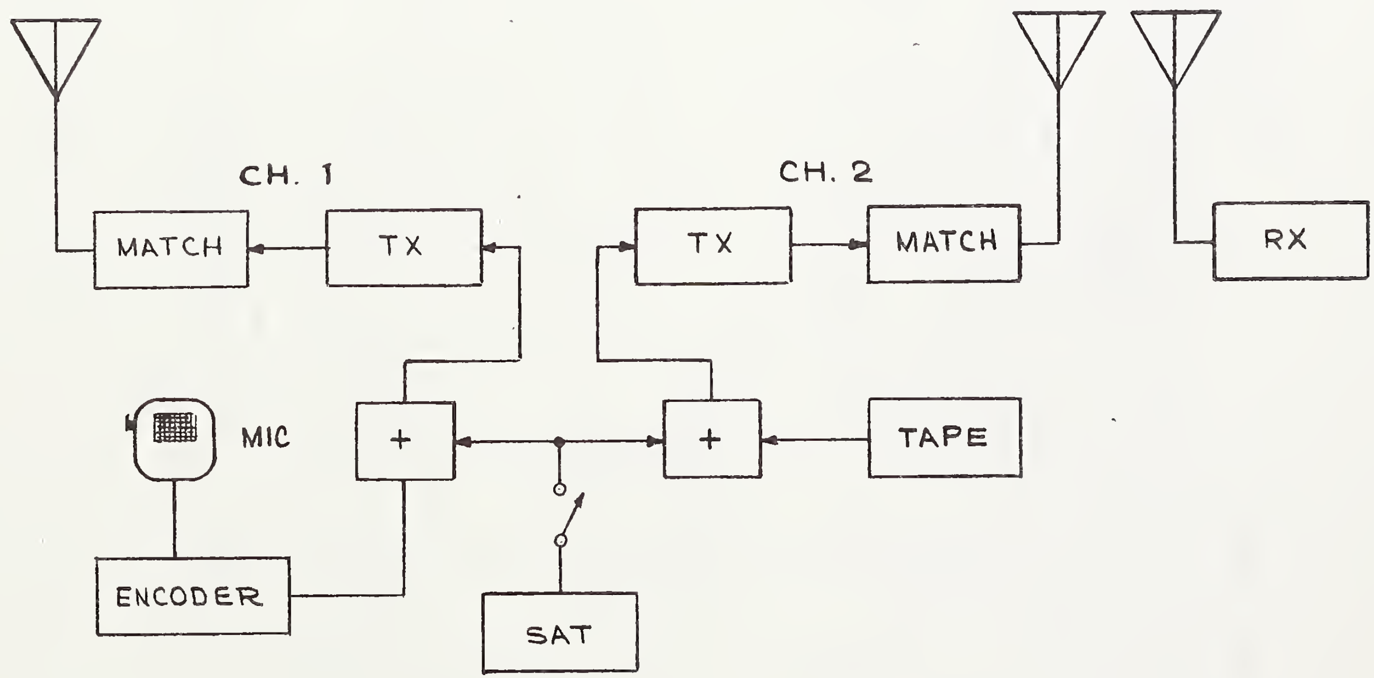
C1 = Channel 1 Code

Voice A = "This is Channel 2. In 5 seconds is the command to switch to Channel 1. 4, 3, 2, 1."

Voice B = "This is Channel 2. This message ends in 5 seconds. 4, 3, 2, 1."

After the receiver switches to Channel 1, follow the same format manually using the Encoder. Check that Channel 2 is not received while on Channel 1, and vice-versa. Automatically switch back to Channel 2 before the end of the 30-second cycle so that the Voice A message can be received again on Channel 2. Transmit on Channel 1 while Channel 2 is being received.

Cycle back and forth between channels several times and observe proper operation of receiver. Perform these tests on each of the receivers. See Figure 49 for proper equipment hookup.



Equipment Setup for Dual-Channel Operation,
Section 3.1.2

Figure 49. Equipment Setup for Dual-Channel Operation.

DATA SHEET

3.1 Channel Selection Tests

3.1.2 Dual-Channel Operation

Date August 8, 1974 Personnel JB/RR

Time 3:00 p.m.

Weather Clear

	Operation O.K. #1	#2	#3
Receiver switches from Ch 1 to Ch 2	x	x	
Receiver switches from Ch 2 to Ch 1	x	x	

3.2 Operation of Message Codes

Set up transmitting system for operation on one channel at a time. Prepare a prerecorded tape for these tests having a format given below. The SAT is also recorded on the tape. The tape format contains the four kinds of messages in a continuous series. The operation of each receiver can be fully checked in all modes during one run of the tape format (5-1/2 minutes). The tests are to be repeated for each receiver on each channel (Figure 50).

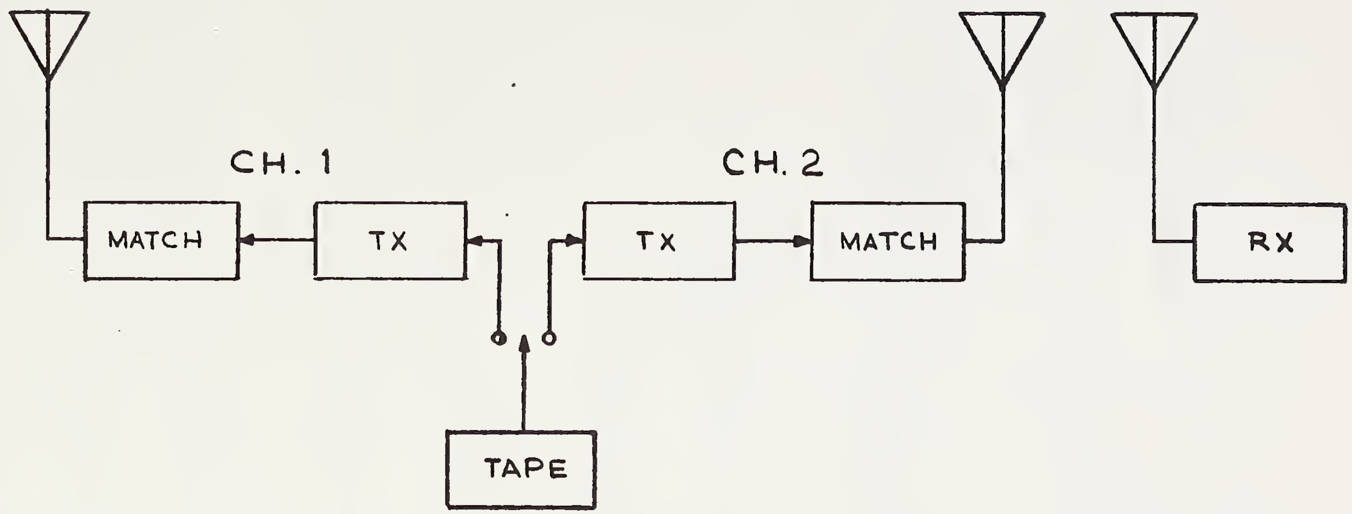
The tape format for these tests is timed to permit adequate testing of the receiver in each mode and, also, to cycle twice in the 5-1/2 minute tape loop. Since the recorder operates at half-speed (3-3/4 ips), this tape loop runs for 11 minutes. The format should be accurately followed and will require rehearsing since the tape will need to run continuously during recording in order that the SAT can also be properly recorded. During the recording, the tape recorder must be operated externally from the Encoder, and the SAT must be interrupted at the prescribed times (Figure 51).

At the indicated times during a message, the channel buttons on each receiver should be depressed to observe the effect on message reception and interlock. Check that the car radio turns off during message reception. Also, check that the car radio turns back on during lockout of the trip advisory and information messages.

<u>Suggested Voice Messages</u>

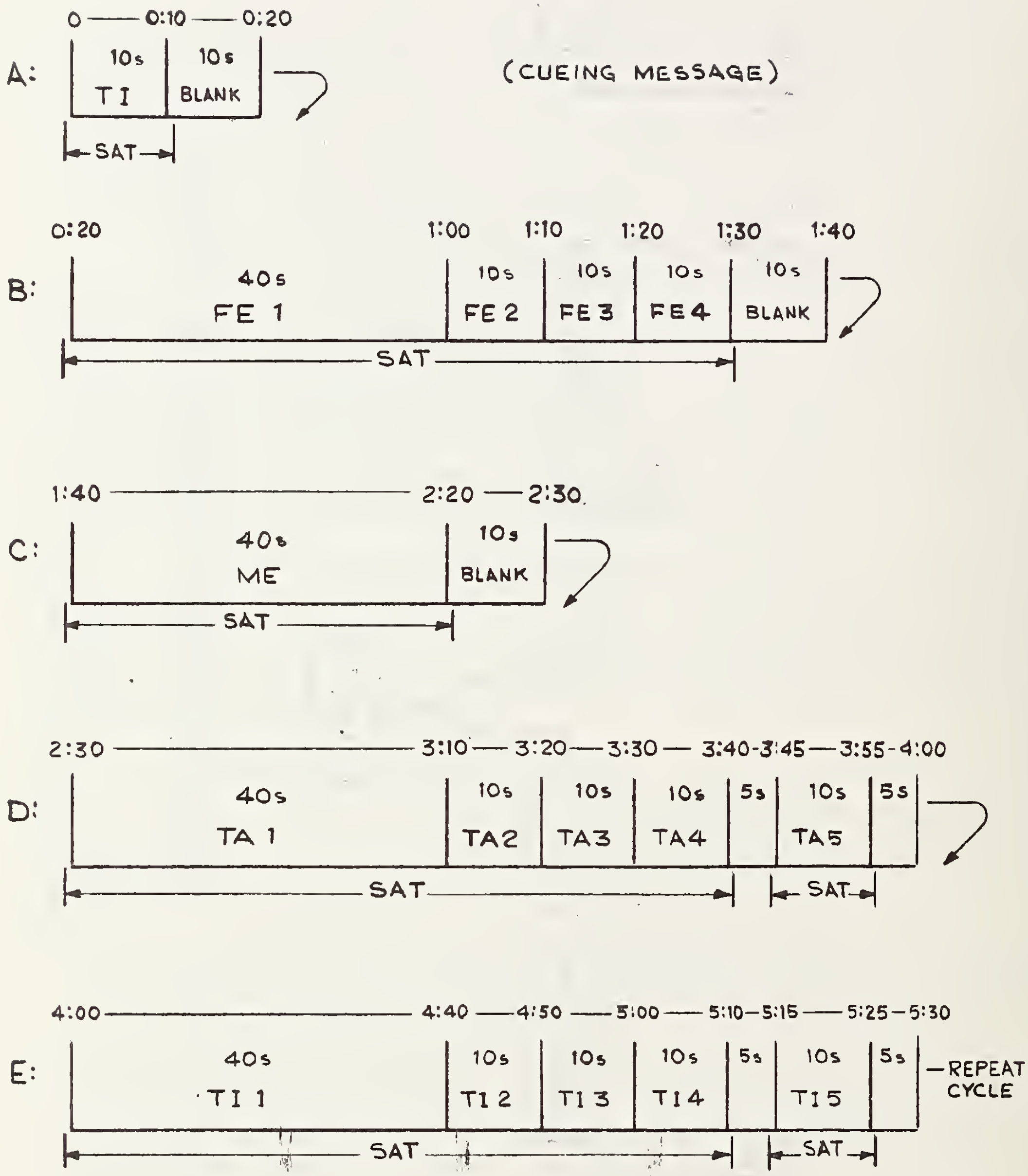
A. "This is the cueing message for the $\left\{\begin{matrix}\text{second}\\\text{first}\end{matrix}\right.$ cycle of tests. Ten seconds after the end of this message, the fixed emergency message will begin."

B. (FE1) "This is the first fixed emergency message which will last 40 seconds. This is experimental station KC2XCM transmitting on 530 kHz or 1606 kHz. Check that the emergency light is on and that this message can be received on all mode positions. There are 20 seconds remaining. Immediately following this message are three 10-second emergency messages which should be received. Pressing either channel button should interrupt this message. There are 10 seconds remaining. This is the first fixed emergency message. 5, 4, 3, 2, 1." (seconds)



Equipment Setup for Operation of Message Codes Testing,
Section 3.2

Figure 50. Equipment Setup for Operation of Message Codes Testing.



FE = Fixed Emergency
ME = Mobile Emergency
TA = Trip Advisory
TI = Trip Information
SAT = Sub Audible Tone

Figure 51. Recorded Tape Message Test Format (0:00 = min:sec).

(FE2) "This is the second fixed emergency message which you should receive. 5, 4, 3, 2, 1."

(FE3) "This is the third fixed emergency message which you should receive. 5, 4, 3, 2, 1."

(FE4) "This is the fourth and last fixed emergency message. The mobile emergency message will begin 10 seconds after this message."

C. (No voice message.)

D. (TA1) "This is the first Trip Advisory message which will last 40 seconds. Check that the emergency light is off and that this message can be heard only in the Trip Advisory and Trip Information modes. Immediately following this message are three 10-second Trip Advisory messages which you should not receive due to lockout unless the channel button is depressed. Thirty-five seconds after the end of this message, you should hear the fifth Trip Advisory message. There are 10 seconds remaining. This is the first Trip Advisory message. 5, 4, 3, 2, 1."

(TA2) "This is the second Trip Advisory message. 5, 4, 3, 2, 1."

(TA3) "This is the third Trip Advisory message. 5, 4, 3, 2, 1."

(TA4) "This is the fourth Trip Advisory message. 5, 4, 3, 2, 1."

(TA5) "This is the fifth Trip Advisory message and should be received. The Trip Information message will begin 5 seconds after the end of this message."

E. (TI1) "This is the first Trip Information message which will last 40 seconds. Check that the emergency light is off and that this message can be heard only in the Trip Information mode. Immediately following this message are three 10-second Trip Information messages which you should not receive due to lockout unless the channel button is depressed. Thirty-five seconds after the end of this message you should hear the fifth Trip Information message. There are 10 seconds remaining. This is the first Trip Information message. 5, 4, 3, 2, 1."

(TI2) "This is the second Trip Information message. 5, 4, 3, 2, 1."

(TI3) "This is the third Trip Information message. 5, 4, 3, 2, 1."

(TI4) "This is the fourth Trip Information message. 5, 4, 3, 2, 1."

(TI5) "This is the fifth Trip Information message and should be received. This is experimental station KC2XCM transmitting on 530 or 1606 kHz."

DATA SHEET

3.2 Operation of Message Codes

Date August 9, 1974 Personnel JB/RR

Time 7:00 p.m.

Weather Clear

		Lights			Audio Receiver			Receiver O.K.		
Tx	Message	Ch 1	Emer	Ch 2	Emer	Adv	Adv Info	#1	#2	#3
Ch 1										
	FE 1	On	On	Off	Yes	Yes	Yes	[X]	[X]	[ ]
	FE 2,3,4	On	On	Off	Yes	Yes	Yes	[X]	[X]	[ ]
	ME	On	Flash	Off	Beep	Beep	Beep	[X]	[X]	[ ]
	TA 1	On	Off	Off	No	Yes	Yes	[X]	[X]	[ ]
	TA 2,3,4	On	Off	Off	No	No	No	[X]	[X]	[ ]
	TA 5	On	Off	Off	No	Yes	Yes	[X]	[X]	[ ]
	TI 1	On	Off	Off	No	No	Yes	[X]	[X]	[ ]
	TI 2,3,4	On	Off	Off	No	No	No	[X]	[X]	[ ]
	TI 5	On	Off	Off	No	No	Yes	[X]	[X]	[ ]
Ch 2	FE 1	Off	On	On	Yes	Yes	Yes	[X]	[X]	[ ]
	FE 2,3,4	Off	On	On	Yes	Yes	Yes	[X]	[X]	[ ]
	ME	Off	Flash	On	Beep	Beep	Beep	[X]	[X]	[ ]
	TA 1	Off	Off	On	No	Yes	Yes	[X]	[X]	[ ]
	TA 2,3,4	Off	Off	On	No	No	No	[X]	[X]	[ ]
	TA 5	Off	Off	On	No	Yes	Yes	[X]	[X]	[ ]
	TI 1	Off	Off	On	No	No	Yes	[X]	[X]	[ ]
	TI 2,3,4	Off	Off	On	No	No	No	[X]	[X]	[ ]
	TI 5	Off	Off	On	No	No	Yes	[X]	[X]	[ ]

Note: Depressing active channel button stops message being received, and next message will be received. Also, depressing button during interlock will cause next message to be received.

Depressing inactive channel button will cause channel change.

4.0 DULLES ACCESS ROAD TESTS

The location of tests conducted on the Dulles Access Road are shown on Figure 52. The test zone extends 4000 feet along a straight section of the highway and is centered at approximately a "Keep Off Median" sign. Horse Pen Road may be used for access in setting up the transmitting systems.

The various transmitting systems to be set up and tested are:

A. Whip Antennas

1. Three antennas for Channel 1,
2. One antenna for Channel 1,
3. Three antennas for Channel 2,
4. One antenna for Channel 2.

B. Leaky Coaxial Cable

1. Commercial cable for Channel 1,
2. Commercial cable for Channel 2,
3. Experimental cable for Channel 1 (optional),
4. Experimental cable for Channel 2 (optional).

4.1 Field Strength Measurements

4.1.1 Three whip antennas. Set up the three whip antennas with matching networks for either channel as shown in Figure 53. Each antenna should be placed approximately 50 feet from the nearest edge of highway pavement. The middle antenna should be located at the center of the test zone. The signal attenuation by the coaxial cables will result in Antenna 2 (center) radiating a stronger signal than Antennas 1 and 3. The differences in signal amplitudes are approximately 3 dB at 530 kHz and 2 dB at 1606 kHz and may be ignored for these tests.

Prior to taking field strength measurements, ensure that the matching network for each antenna is properly adjusted: maximum radiated signal and minimum VSWR in transmitter cables. Also, be sure the transmitter is tuned for maximum power output. Measure the transmitter output level.

The transmitting signal is a carrier that is either unmodulated or modulated by a single audio tone for identification. Obtain absolute field

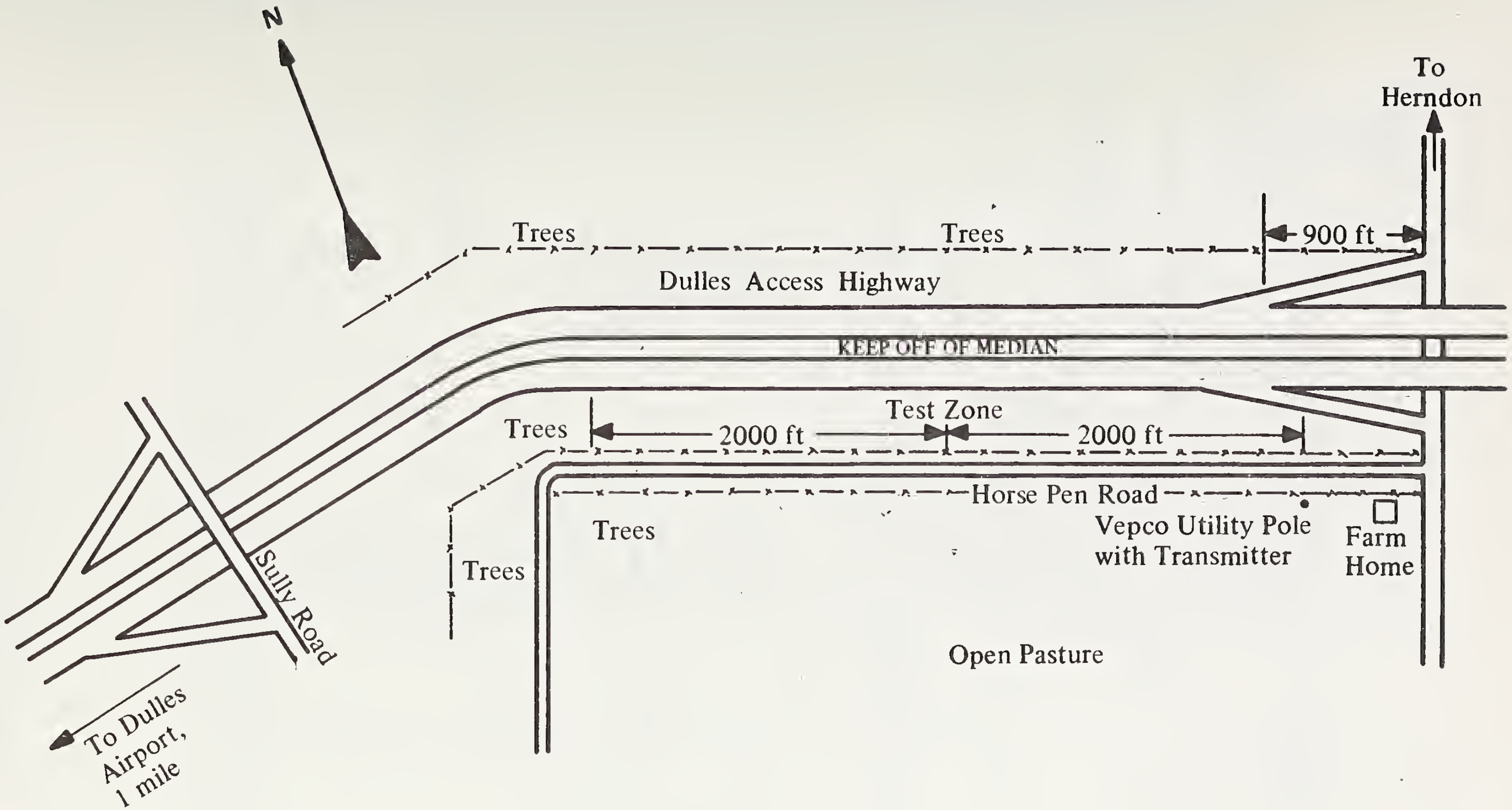
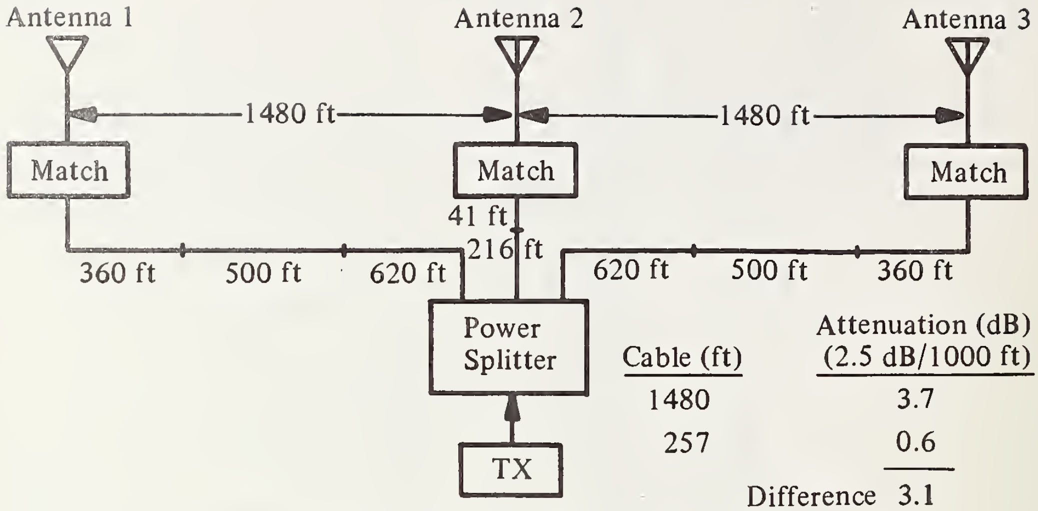
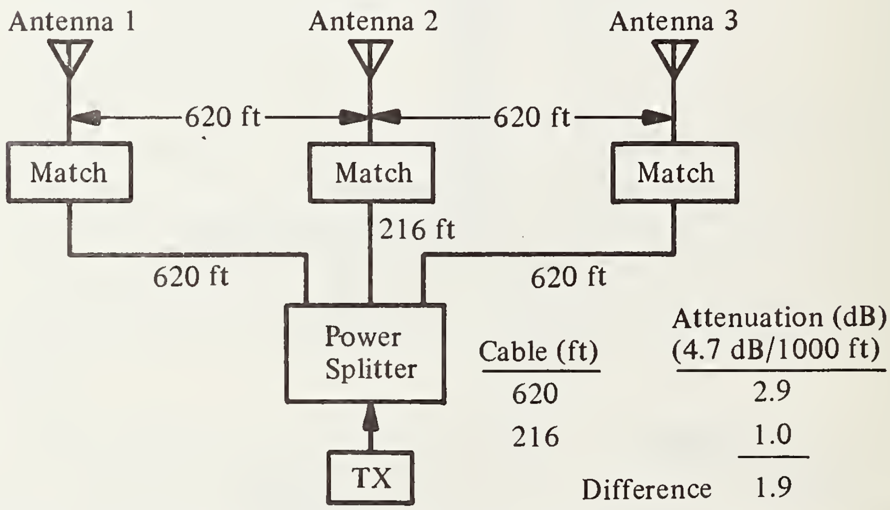


Figure 52. Map of Test Zone on Dulles Access Highway.



Antenna Spacings and RG-58 Cable Connections for 530 kHz



Antenna Spacings and RG-58 Cable Connections for 1606 kHz

Figure 53. Antenna Array Spacings and Cable Lengths.

DATA SHEET

4.1.1 Field Strength with Three Antennas (Dulles Highway)

Date July 5, 1974 Personnel JB/RR

Time 2:00 p.m. Rx Equipment FIM-41

Weather Clear

Ch. 1 (530 kHz) Tx Level 5.0 watts Rx Cal. Factor 35.5 dB

Position (feet)	Field Strength (South Lane)	Field Strength (North Lane)	Position (feet)	Field Strength (South Lane)	Field Strength (North Lane)
WEST	* (mV/m)		EAST	* (mV/m)	
0	7.0	*	0	7.0	*
50	6.0		50	5.8	
100	4.3		100	3.7	
150	2.2		150	1.7	
200	1.0	*	200	0.90	*
300	0.42		300	0.40	
400	0.25	*	400	0.25	*
500	0.19		500	0.18	
600	0.18	*	600	0.17	*
700	0.18		700	0.17	
800	0.18	*	800	0.18	*
900	0.18		900	0.18	
1000	0.19	*	1000	0.17	*
1100	0.21		1100	0.19	
1200	0.28		1200	0.31	
1300	0.65		1300	0.78	
1350	1.0		1350	1.6	
1400	2.0		1400	3.4	
1480	5.2	*	1480	6.5	*
1550	3.0		1550	4.2	
1600	1.15	*	1600	1.4	*
1650	0.80		1650	0.80	
1700	0.58		1700	0.60	
1800	0.35	*	1800	0.34	*
1900	0.21		1900	0.22	
2000	0.15	*	2000	0.18	*

*Reading recommended.
Readings were taken along shoulder of South Lane to eliminate possibility of creating a hazard on highway with slow moving instrumented van.

DATA SHEET

4.1.1 Field Strength with Three Antennas (Dulles Highway)

Date June 4, 1974 Personnel JB/JD

Time 10:00 a.m. Rx Equipment FIM-41

Weather Cloudy

Ch. 2 (1606 kHz) Tx Level 2.2 watts Rx Cal. Factor 35.5 dB

Position (feet)	Field Strength (South Lane)	Field Strength (North Lane)	Position (feet)	Field Strength (South Lane)	Field Strength (North Lane)
WEST	* (mV/m)		EAST	* (mV/m)	
0	16.0	*	0	16.0	*
50	12.2		50	11.8	
100	8.5		100	8.9	
150	6.0		150	4.2	
200	5.0	*	200	4.5	*
250	7.5		250	6.5	
300	8.8		300	8.0	
350	9.0	*	350	8.8	*
400	8.0		400	7.5	
450	4.4	*	450	5.8	*
500	4.0		500	5.5	
550	8.0		550	7.2	
600	10.0	*	600	10.5	*
650	13.5		650	11.2	
700	9.5		700	9.0	
800	7.0	*	800	6.8	*
1000	4.2		1000	4.0	
1200	2.7	*	1200	2.7	*
1400	1.8		1400	1.9	
1600	1.5		1600	1.5	
1800	1.0		1800	1.8	
2000	0.77	*	2000	1.0	*

*Reading recommended

Readings along shoulder of South Lane.

strength readings with a calibrated receiving system. The use of an H-field loop antenna may be used; however, see Section 2.0 #7. The readings are to be taken along the nearest (Eastbound) lane of the Dulles Access Road at points separated by intervals sufficiently small to permit an accurate determination of the field strength profile over the entire test zone. Figures 54 and 55 show theoretical curves of the field strength expected for one watt delivered to each antenna. Actual measured values may differ by as much as 20 dB from those shown due to an unknown ground loss factor. Other causes for discrepancies are:

1. Terrain variations along the test zone,
2. Differences in earth conductivity around each antenna,
3. Unequal phase shifts in each matching network,
4. Reradiation from the shields of the coaxial cables.

As shown by the field strength curves, measurements should be taken at 50 or 100-foot intervals in regions of the nulls; otherwise, the intervals can be several hundred feet where the field varies uniformly. At each measurement point, the receiving loop should be held in a vertical plane and rotated in azimuth for maximum signal. The data sheets for these measurements give suggested measurement locations. A limited number of field measurements should be taken along the opposite side (Westbound lane) of the highway.

4.1.2 Single whip antenna. Disconnect Antennas 1 and 3 and transmit only from the central antenna, Antenna #2. If the power splitter is kept in the circuit, place suitable 50-ohm terminations on the two unused ports. Otherwise, connect the transmitters directly into the Antenna 2 matching network.

Follow all applicable test procedures described in Section 4.1.1.

4.1.3 Commercial Leaky Coaxial Cable. Place the cable on the ground parallel to and 50 feet from the nearest pavement of the Dulles Access Road. The midpoint of the cable should be at the center of the test zone. Connect the transmitter to one end of the cable. If the characteristic impedance of the cable is significantly different from 50 ohms, a matching transformer may be required. Terminate the other end of the cable with a resistive load equal to the characteristic impedance of the cable.

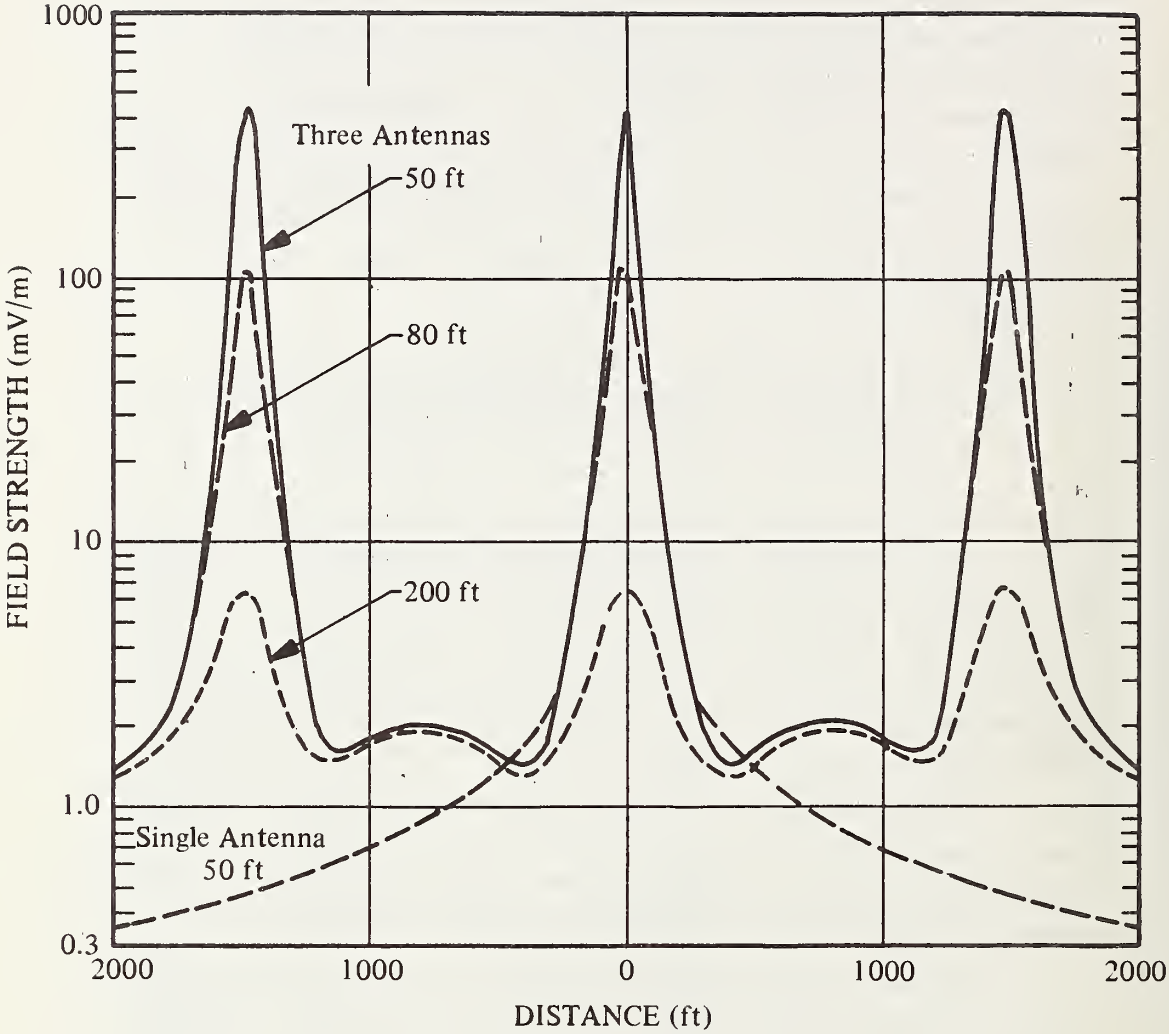


Figure 54. Calculated Field Strength for Whip Antenna Array at 530 kHz.

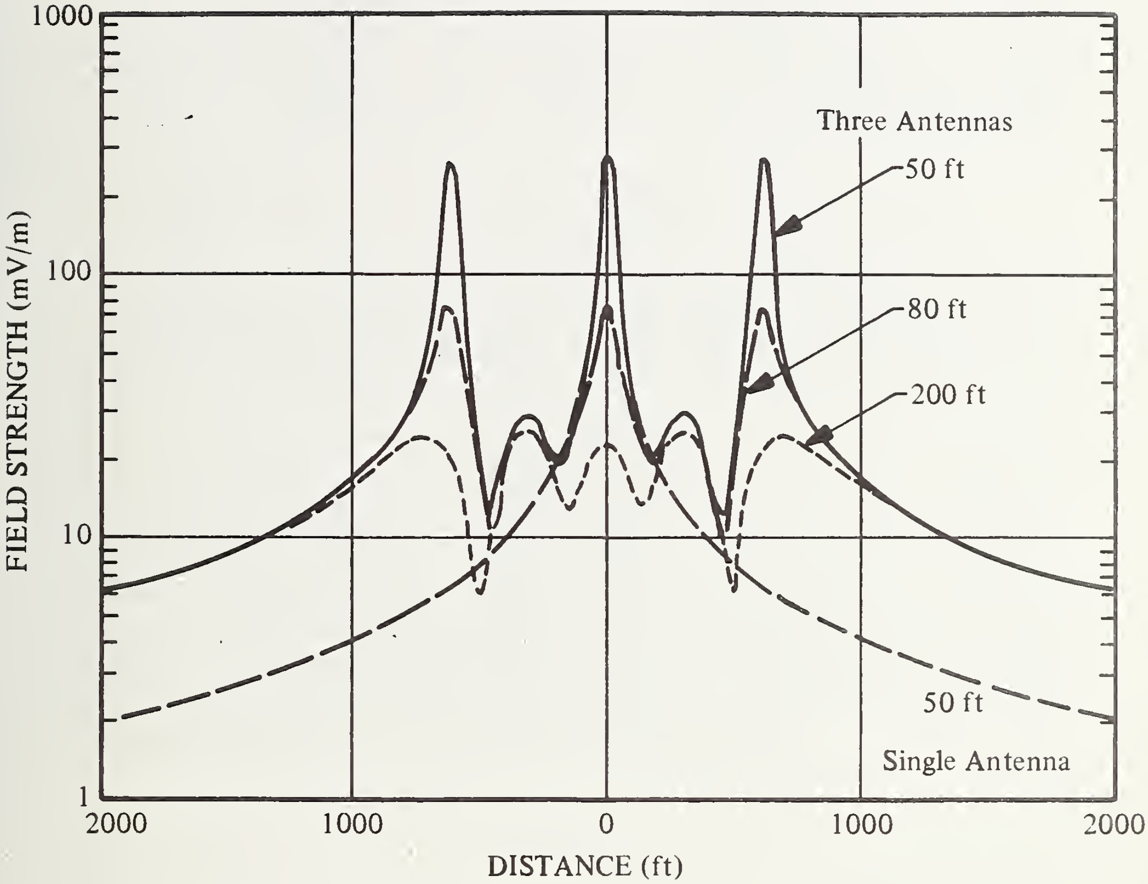


Figure 55. Calculated Field Strength for Whip Antenna Array at 1606 kHz.

DATA SHEET

4.1.2 Field Strength with Single Antenna (Dulles Highway)

Date July 5, 1974 Personnel JB/JD

Time 3:00 p.m. Tx To center antenna directly

Weather Clear Rx FIM-41

Ch. 1 (530 kHz) Tx Level 0.5 watts Rx Cal. Factor 35.5 dB

Position (feet)	Field Strength (South Lane)	Field Strength (North Lane)	Position (feet)	Field Strength (South Lane)	Field Strength (North Lane)
WEST	* (mV/m)		EAST	* (mV/m)	
0	16.0	*	0	16.0	*
100	10.5		100	10.0	
200	3.7		200	3.0	
400	0.95	*	400	0.96	*
800	0.35		800	0.39	
1200	0.19	*	1200	0.23	*
1600	0.13		1600	0.16	
2000	0.09	*	2000	0.12	*

*Reading recommended

Readings along shoulder of South Lane.

DATA SHEET

4.1.2 Field Strength with Single Antenna (Dulles Highway)

Date June 4, 1974 Personnel JB/JD

Time 1:00 p.m. Tx To center antenna directly

Weather Cloudy Rx FIM-41

Ch. 2 (1606 kHz) Tx Level 0.5 watts Rx Cal. Factor 35.5 dB

Position (feet)	Field Strength (South Lane)	Field Strength (North Lane)	Position (feet)	Field Strength (South Lane)	Field Strength (North Lane)
EAST	* (mV/m)		WEST	* (mV/m)	
0	31.0	*	0	31.0	*
100	14.5		100	16.5	
200	8.0		200	9.2	
400	3.5	*	400	3.8	*
800	1.4		800	1.4	
1200	0.90	*	1200	0.90	*
1600	0.70		1600	0.65	
2000	0.62	*	2000	0.50	*

*Reading recommended

Readings along shoulder of South Lane.

DATA SHEET

4.1.3, 4.1.4 Field Strength with Leaky Cable (Dulles Highway)

Date August 25, 1974 Personnel JB/RR

Time 4:00 pm Tx HAIR unit directly to cable

Weather Clear Rx FIM-41

Type of Cable RTV induction cable

Ch. 1 (530 kHz) Tx Level 10 watts Rx Cal. Factor 35.5 dB

Position (feet)	Field Strength (South Lane)	Field Strength (North Lane)	Position (feet)	Field Strength (South Lane)	Field Strength (North Lane)
EAST	mV/m	mV/m	WEST	mV/m	mV/m
0	2.1	0.89	0	2.1	0.89
50	1.18	0.59	50	1.5	0.92
100	1.92	0.92	100	1.5	0.92
150	1.92	1.18	150	1.3	1.18
200	0.92	0.75	200	2.0	1.10
250	0.75	0.70	250	1.9	0.75
300	1.2	0.75	300	2.9	1.20
350	2.9	2.00	350	1.1	0.70
400	2.9	0.97	400	0.8	0.40
450	0.6	0.41	450	0.6	0.60
500	0	0	500	0	0

Readings taken at am auto antenna position on car for both lanes (right side of vehicle). Measurement separation distance between lanes = 12 feet.

With the transmitter properly tuned, obtain a measurement of the transmitter output and proceed with field strength measurements along the highway as described in Section 4.1.1. As a minimum, take a reading at each peak and null of the field pattern.

4.1.4 Experimental Leaky Cable (Optional). A "leaky" transmitting cable equivalent to the commercial coaxial type may be constructed in a number of ways. The simplest approach is to use a single conductor, such as the RG-58 shield, laid along the ground and fed against a ground rod terminal. Another method is to spiral-wrap the RG-58 around a long section of RG-9 and feed one shield against the other. In each case, the opposite end should be properly terminated to minimize standing waves in the line.

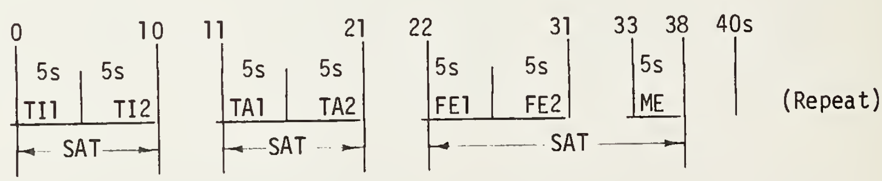
Follow the same measurement procedure used for Section 4.1.3.

4.2 System Operational Tests

This final series of tests will serve not only to check system performance with the receivers in a moving vehicle but, also, will demonstrate the over-all system operation in a realistic environment. For each transmitting system setup, the total system (for one channel only) will be operated from a prerecorded tape loop containing a sequence of all the message modes which will permit all mode functions to be tested on each receiver in a vehicle during one pass through the test zone area.

The object of the present tests is to observe operational performance with the receivers located within moving vehicles and with various kinds of transmitting antenna systems. Possible disturbances from ignition noise of nearby vehicles on the receiving system will be examined to a limited extent during these tests. Also, for a given transmitting system and power level, the maximum range of system will be determined. Finally, these tests will permit an evaluation to be made of the audio fidelity and stability of voice messages received while the vehicle is moving at high speed through the test zone.

The tape message test format is shown below and represents an abbreviated version of that used in Section 3.2. The complete format can be recorded on one "20s" tape loop which lasts 40 seconds. The SAT will have to be recorded on the tape but must be interrupted between different message modes as indicated.



where

TI = Trip Information message

TA = Trip Advisory message

FE = Fixed Emergency message

ME = Mobile Emergency

Each message (except ME) should contain voice identification. Periodically, the experimental license call letters should also be identified as required by FCC regulations.

The data sheet is general and copies can be used for each test combination of transmitting system and channel frequency.

DATA SHEET

4.2 System Operational Tests

Date August 22, 1974
Rerun October 15, 1974

Personnel JB/RR

Time 1 - 3:00 p.m.

Weather Clear

Tx System 3-antenna array

Tx Output Level 10 watts

Tx	Message	Lights Ch. 1	Lights Emer	Lights Ch. 2	Audio Received* Emer	Audio Received* Adv	Audio Received* Adv Info	Receiver O.K. #1	Receiver O.K. #2	Receiver O.K. #3
Ch. 1	TI 1	___	Off	___	No	No	Yes	☒	☒	☐
	TI 2		Off		No	No	No	☒	☒	☐
	TA 1		Off		No	Yes	Yes	☒	☒	☐
	TA 2		Off		No	No	No	☒	☒	☐
	FE 1		On		Yes	Yes	Yes	☒	☒	☐
	FE 2		On		Yes	Yes	Yes	☒	☒	☐
	ME		On		Beep	Beep	Beep	☒	☒	☐

*Assuming the channel buttons are not pushed.

Comments:

Effect of local ignition noise: No disturbance from nearby vehicles; ignition noise of test car affects sensitivity of adapter unit, higher speeds knock out signal at lower levels. No noise effect on integrated unit.

Audio fidelity, stability, and power level: Stability of voice message satisfactory when receivers capture signal. Audio fidelity is slightly noisy. Poor sensitivity of receivers produces dead zones within 4000-foot coverage, receiver sensitivity can be improved with alignment and tuning of RF traps.*

Maximum range (eastbound) that system operates reliably: Receivers function OK when captured. Receiver sensitivity in terms of minimum field strength to operate is low: e.g., Adapter = 330 $\mu v/m$; Integrated = 1.5 mV/m.

*Rerun October 15, 1974: Receiver sensitivity of both units improved ≈ 20 $\mu v/m$; integrated worked perfectly: adapter, some intermittent but can be attributed to field strength problem. Maximum range is 500 feet beyond end of zone.

DATA SHEET

4.2 System Operational Tests

Date August 22, 1974
Rerun: October 14, 1974

Personnel JB/RR

Time 3 - 6:00 p.m.

Weather Clear

Tx System 3-antenna array

Tx Output Level 10 watts

Tx	Message	Lights Ch. 1	Lights Emer	Lights Ch. 2	Audio Received* Emer	Audio Received* Adv	Audio Received* Adv Info	Receiver O.K. #1	Receiver O.K. #2	Receiver O.K. #3
Ch. 2	TI 1	___	Off	___	No	No	Yes	[X]	[X]	[X]
	TI 2		Off		No	No	No	[X]	[X]	[X]
	TA 1		Off		No	Yes	Yes	[X]	[X]	[X]
	TA 2		Off		No	No	No	[X]	[X]	[X]
	FE 1		On		Yes	Yes	Yes	[X]	[X]	[X]
	FE 2		On		Yes	Yes	Yes	[X]	[X]	[X]
	ME		On		Beep	Beep	Beep	[X]	[X]	[X]

*Assuming the channel buttons are not pushed.

Comments:

Effect of local ignition noise No effect.

Audio fidelity, stability, and power level: Stability of voice message constant throughout coverage zone. Audio fidelity slightly noisy. Power level throughout coverage zone satisfactory. Receivers satisfied all mode functions.

Maximum range (eastbound) that system operates reliably: 2000 feet: Performance satisfactory throughout 4000-foot coverage zone: Significant improvement in sensitivity and field strength in rerun of October 14, 1974. Range can be extended well beyond end of zone (if desired) by power adjustment.

DATA SHEET

4.2 System Operational Tests

Date August 26, 1974 Personnel JB/RR

Time 11:00 a.m.

Weather Clear

Tx System RTV induction cable Tx Output Level 10 watts

Tx	Message	Lights Ch. 1	Lights Emer	Lights Ch. 2	Audio Received* Emer	Audio Received* Adv	Audio Received* Adv Info	Receiver O.K. #1	Receiver O.K. #2	Receiver O.K. #3
Ch. 1	TI 1	___	Off	___	No	No	Yes	[X]	[X]	[ ]
	TI 2		Off		No	No	No	[X]	[X]	[ ]
	TA 1		Off		No	Yes	Yes	[X]	[X]	[ ]
	TA 2		Off		No	No	No	[X]	[X]	[ ]
	FE 1		On		Yes	Yes	Yes	[X]	[X]	[ ]
	FE 2		On		Yes	Yes	Yes	[X]	[X]	[ ]
	ME		On		Beep	Beep	Beep	[X]	[X]	[ ]

*Assuming the channel buttons are not pushed. (see comment)

Comments:

Effect of local ignition noise: Minimum

Audio fidelity, stability, and power level: Audio fidelity same as antenna system; i.e., slightly noisy. Stability - OK; generally, power level adequate, but with some marginal areas where receivers did not capture message causing intermittent operation of about 10%. Receivers satisfy mode function when capture signal.

Maximum range (eastbound) that system operates reliably: Coverage zone is length of cable = 1000 feet.

Note: October 15, 1974

Receivers sensitivity improved significantly $\simeq$ 20 dB. Although not tested at this time, it is felt that receiver would operate without intermittent operation.

DATA SHEET

4.2 System Operational Tests

Date August 24, 1974 Personnel JB/RR

Time 7:00 p.m.

Weather Clear

Tx System RTV induction cable Tx Output Level 10 watts

		Lights			Audio Received*			Receiver O.K.		
Tx	Message	Ch. 1	Emer	Ch. 2	Emer	Adv	Adv Info	#1	#2	#3
Ch. 2	TI 1	___	Off	___	No	No	Yes	[X]	[X]	[ ]
	TI 2		Off		No	No	No	[X]	[X]	[ ]
	TA 1		Off		No	Yes	Yes	[X]	[X]	[ ]
	TA 2		Off		No	No	No	[X]	[X]	[ ]
	FE 1		On		Yes	Yes	Yes	[X]	[X]	[ ]
	FE 2		On		Yes	Yes	Yes	[X]	[X]	[ ]
	ME		On		Beep	Beep	Beep	[X]	[X]	[ ]

*Assuming the channel buttons are not pushed.

Comments:

Effect of local ignition noise: None

Audio fidelity, stability, and power level: Audio fidelity same as with antenna system, slightly noisy. Stability good. Power level satisfactory along cable. Receivers functioned satisfactory when tested in both lanes.

Maximum range (eastbound) that system operates reliably: Coverage zone is confined to length of cable (1000 feet); field strength fails off rapidly beyond end of cable.

DATA SHEET

4.2 System Operational Tests

Date August 26, 1974 Personnel JB/RR

Time 5:00 p.m.

Weather Clear

Tx System Andrews Cable - RX 4-3A Tx Output Level 10 watts

Tx	Message	Lights			Audio Received*			Receiver O.K.		
		Ch. 1	Emer	Ch. 2	Emer	Adv	Adv Info	#1	#2	#3
Ch. 1	TI 1	___	Off	___	No	No	Yes	[x]	[x]	[ ]
	TI 2		Off		No	No	No	[x]	[x]	[ ]
	TA 1		Off		No	Yes	Yes	[x]	[x]	[ ]
	TA 2		Off		No	No	No	[x]	[x]	[ ]
	FE 1		On		Yes	Yes	Yes	[x]	[x]	[ ]
	FE 2		On		Yes	Yes	Yes	[x]	[x]	[ ]
	ME		On		Beep	Beep	Beep	[x]	[x]	[ ]

*Assuming the channel buttons are not pushed.

Comments:

Effect of local ignition noise : Minimum

Audio fidelity, stability, and power level: Audio fidelity slightly noisy. Slight variation in audio stability. Adapter unit satisfies mode functions when receiver captures signal, however, marginal power level and poor receiver sensitivity caused intermittent operation.

Maximum range (eastbound) that system operates reliably: Coverage zone is confined to length of cable (1000 feet); field strength falls off rapidly beyond end of cable.

Note: October 15, 1974

Receivers sensitivity improved significantly ≈ 20 dB. Although not tested at this time, it is felt that receiver would operate without intermittent operation.

DATA SHEET

4.2 System Operational Tests

Date August 24, 1974 Personnel JB/RR

Time 4:00 p.m.

Weather Clear

Tx System Andrews cable - RX4-3A Tx Output Level 10 watts

Tx	Message	Lights Ch. 1	Lights Emer	Lights Ch. 2	Audio Received* Emer	Audio Received* Adv	Audio Received* Adv Info	Receiver O.K. #1	Receiver O.K. #2	Receiver O.K. #3
Ch. 2	TI 1	___	Off	___	No	No	Yes	X	X	
	TI 2		Off		No	No	No	X	X	
	TA 1		Off		No	Yes	Yes	X	X	
	TA 2		Off		No	No	No	X	X	
	FE 1		On		Yes	Yes	Yes	X	X	
	FE 2		On		Yes	Yes	Yes	X	X	
	ME		On		Beep	Beep	Beep	X	X	

*Assuming the channel buttons are not pushed.

Comments:

Effect of local ignition noise : None

Audio fidelity, stability, and power level: Audio fidelity same as with antenna system, slightly noisy. Stability - good. Power level satisfactory . Receivers satisfied mode functions when tested in both lanes.

Maximum range (eastbound) that system operates reliably: Coverage zone is confined to length of cable (1000 feet).

APPENDIX D

SYSTEM CIRCUIT DIAGRAMS

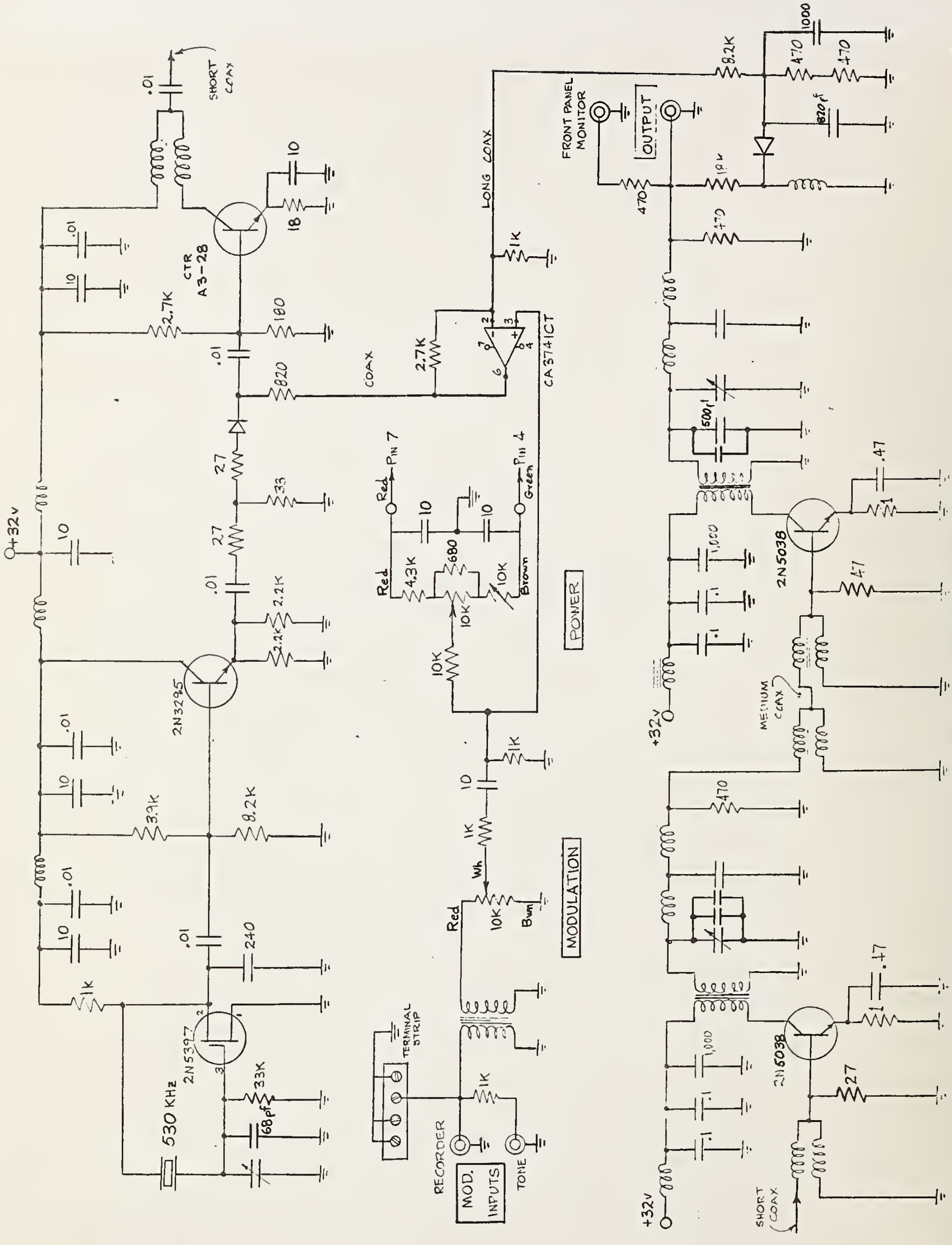


Figure 56. 530 kHz Transmitter.

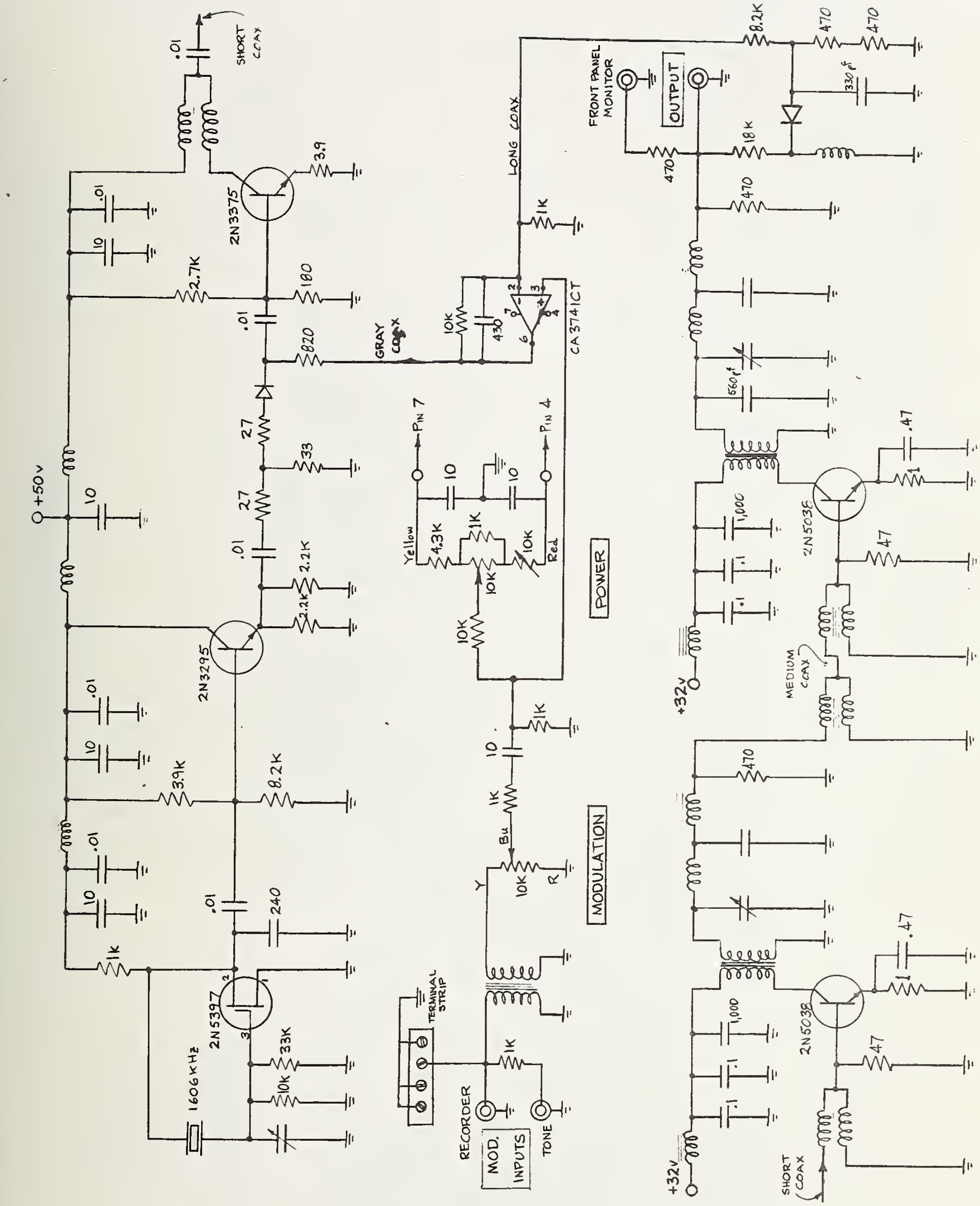


Figure 57. 1606 kHz Transmitter.

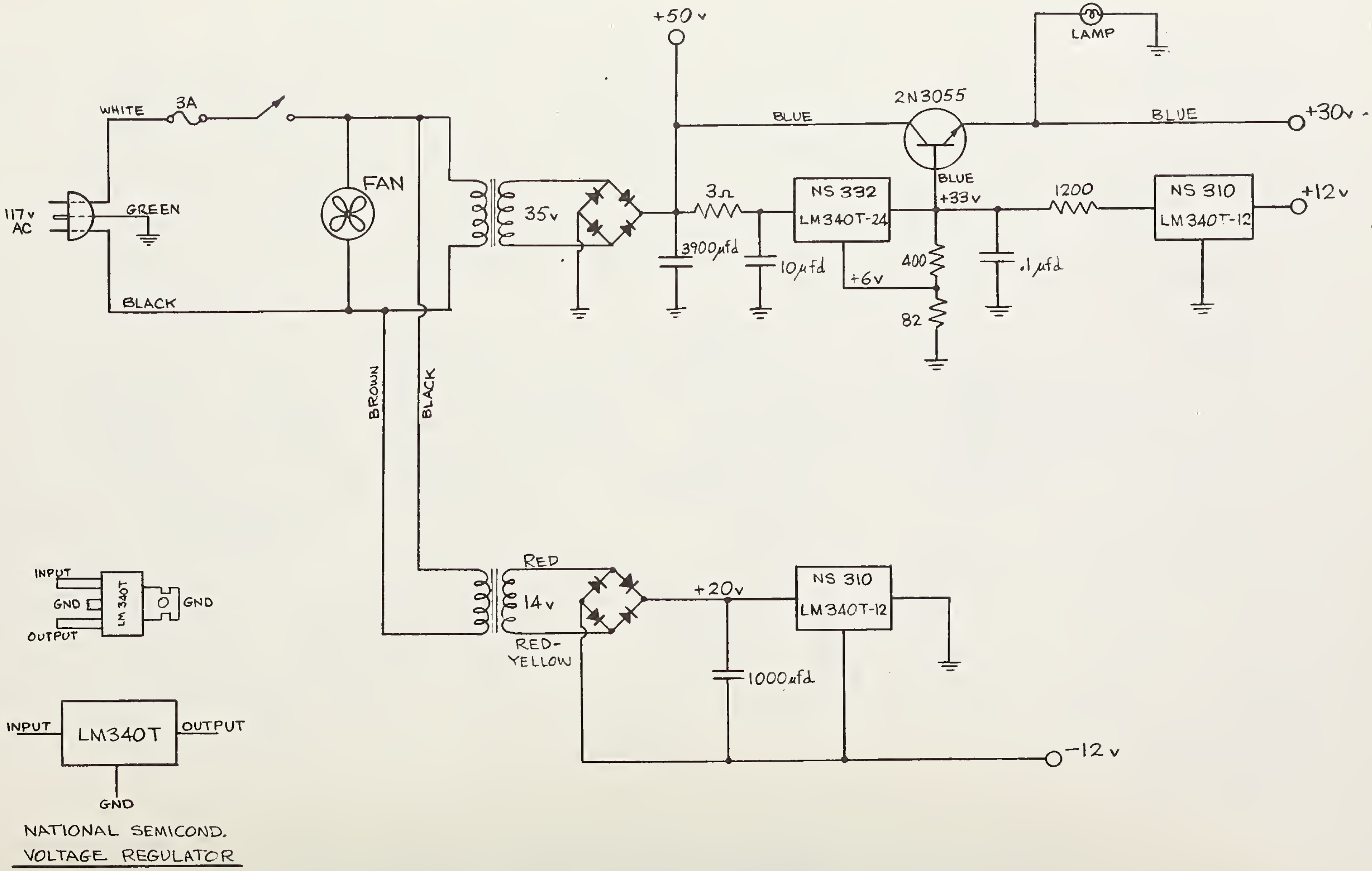


Figure 58. Transmitter Power Supply.

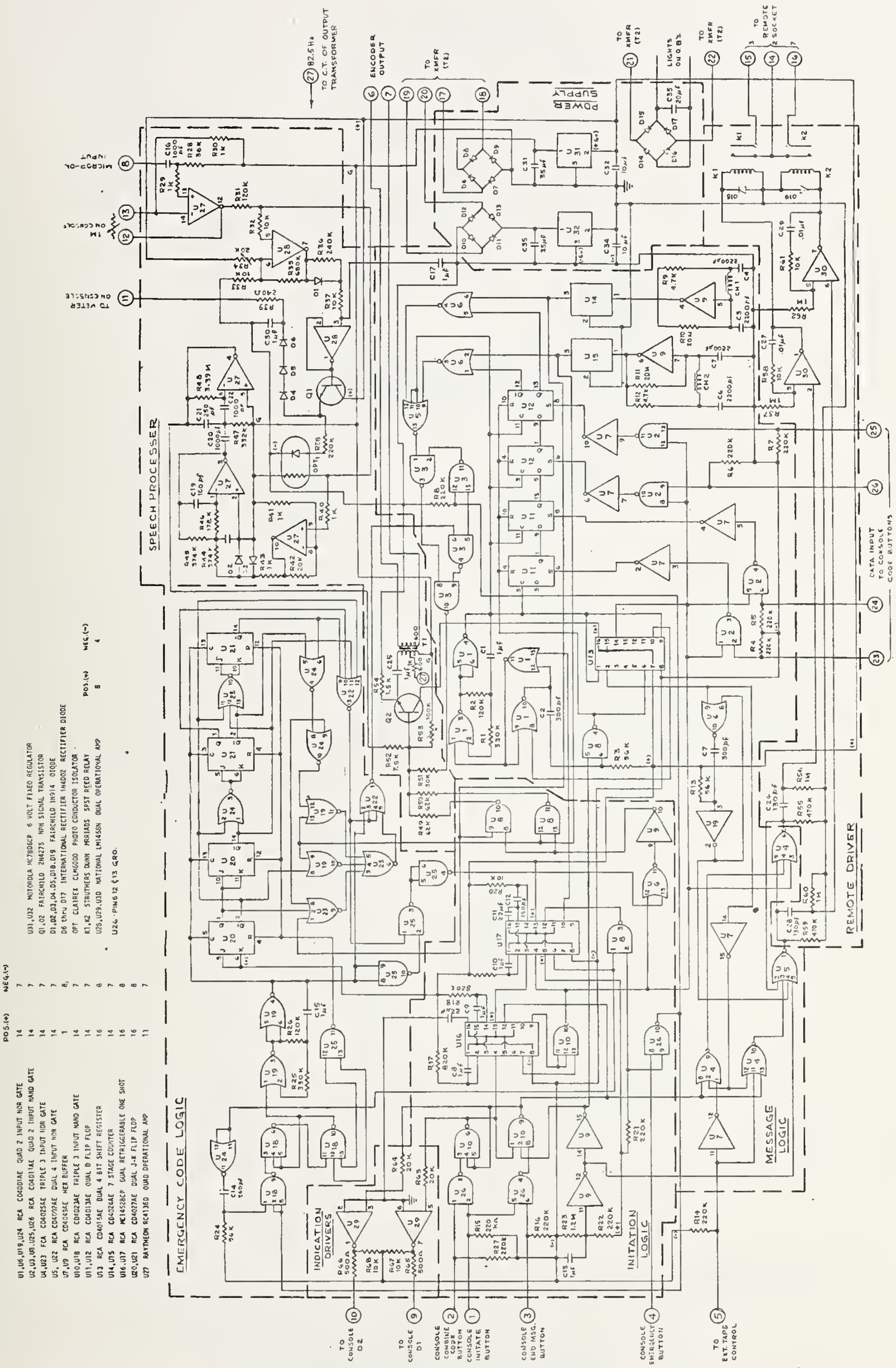


Figure 59. Encoder Circuit Board.

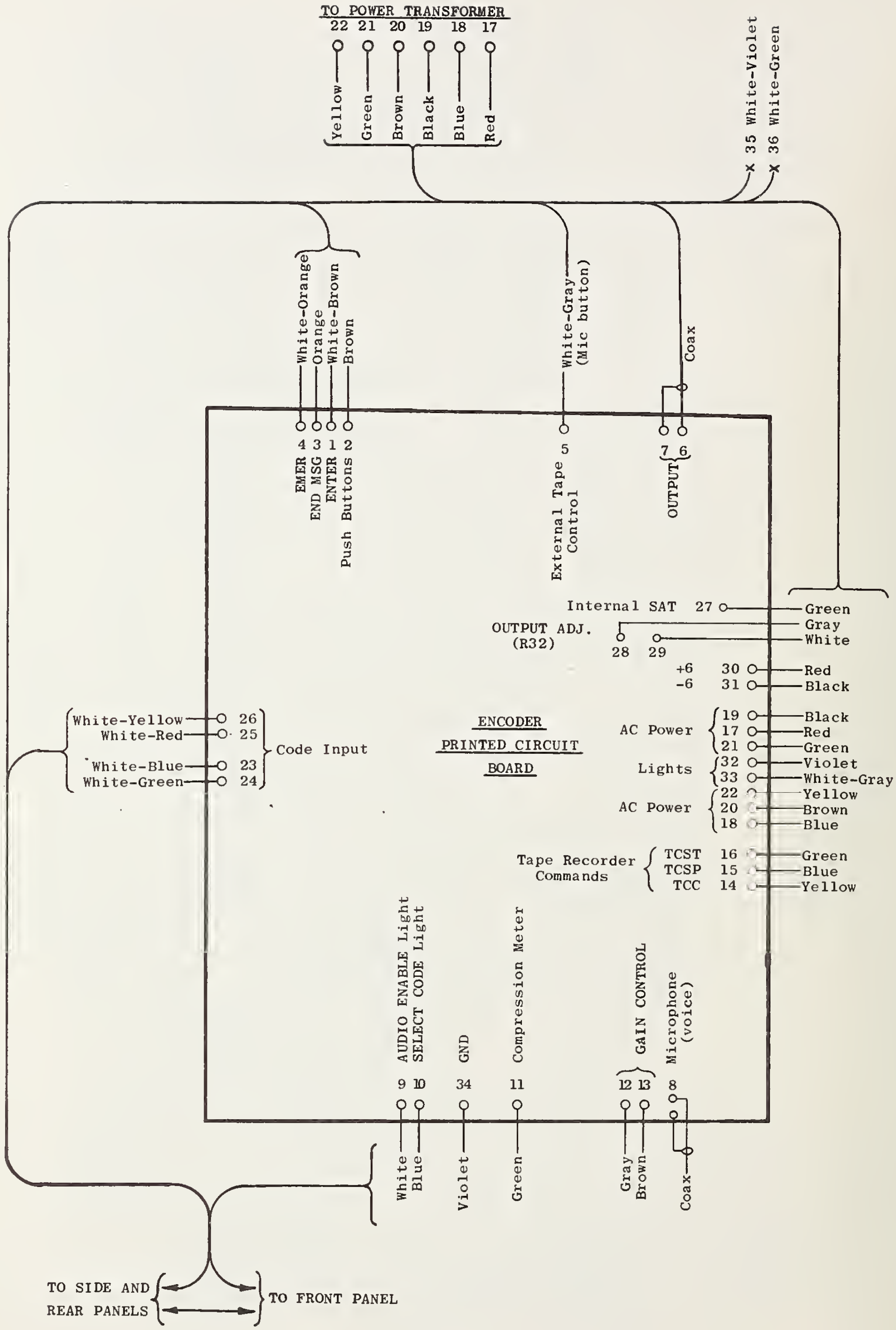


Figure 60. Encoder Wiring Layout.

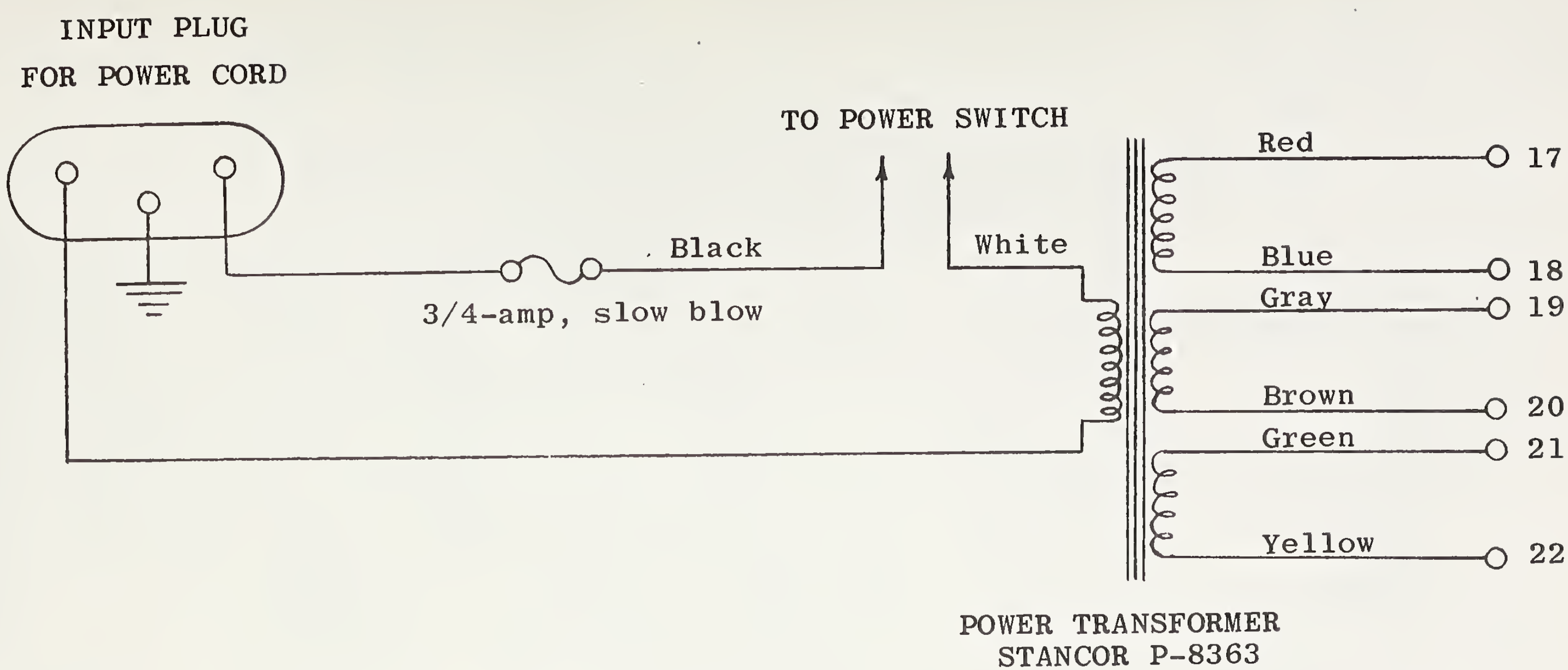


Figure 61. Encoder Power Transformer.

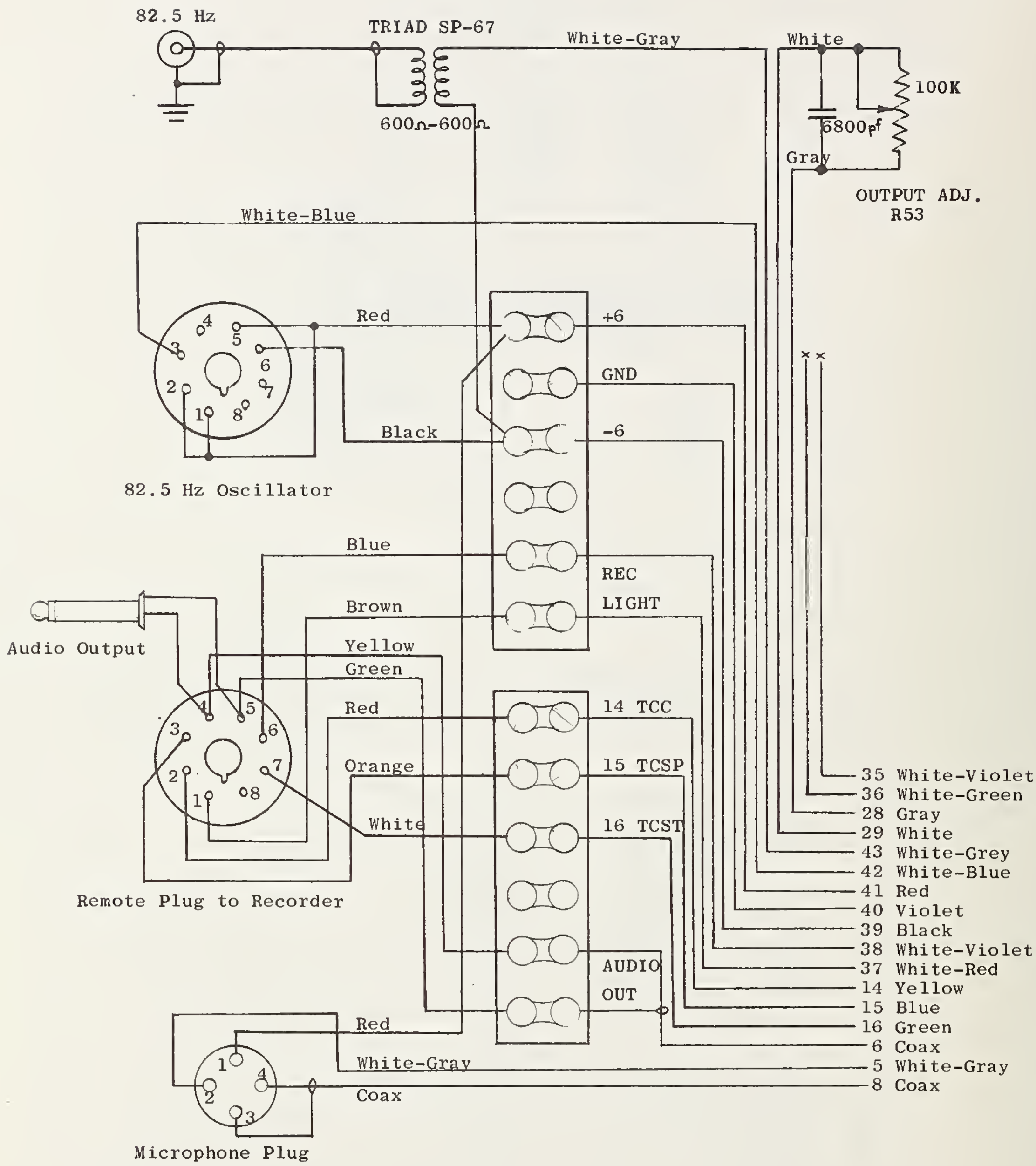


Figure 62. Encoder Side and Rear Panel Wiring.

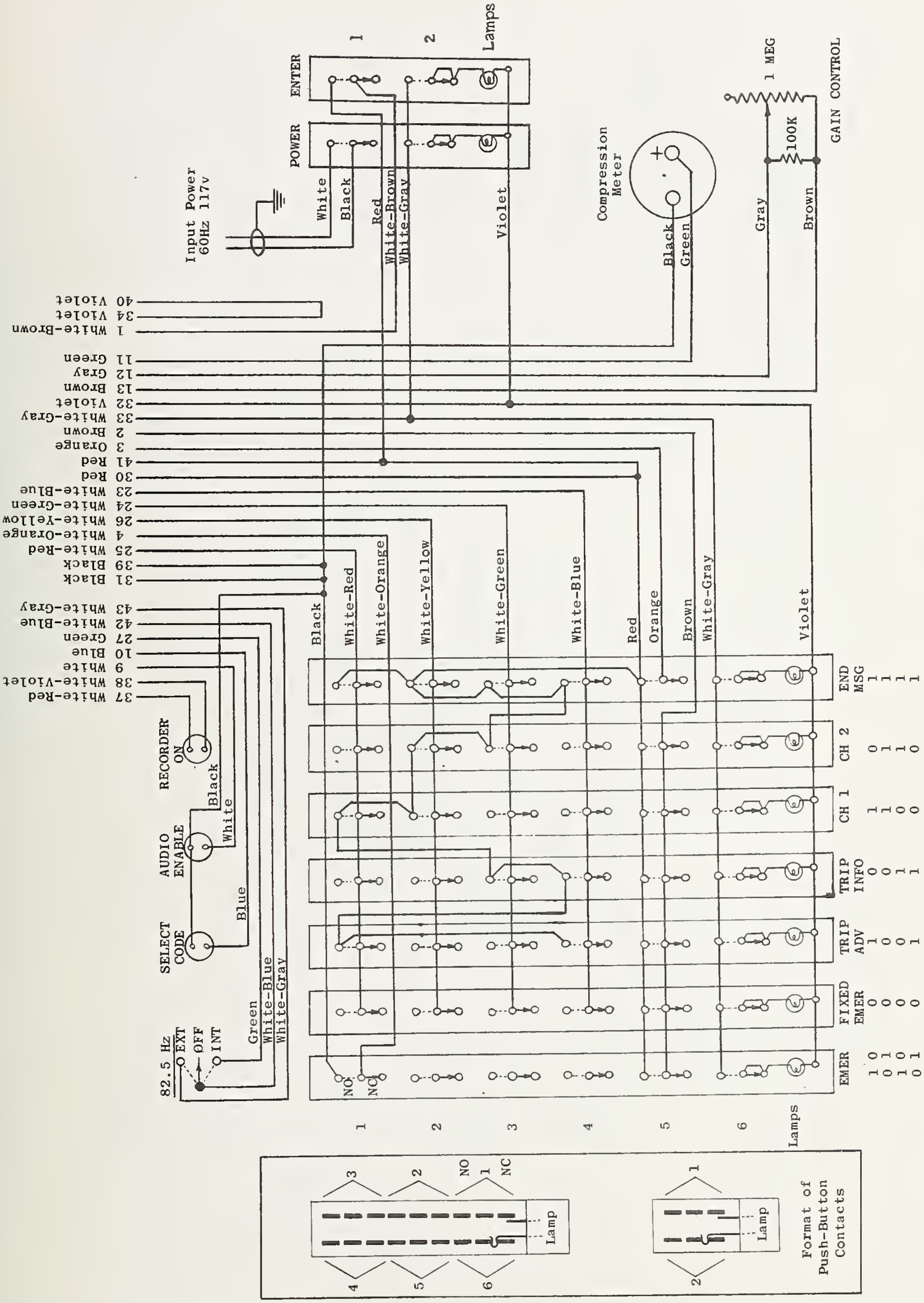


Figure 63. Encoder Front Panel Wiring.

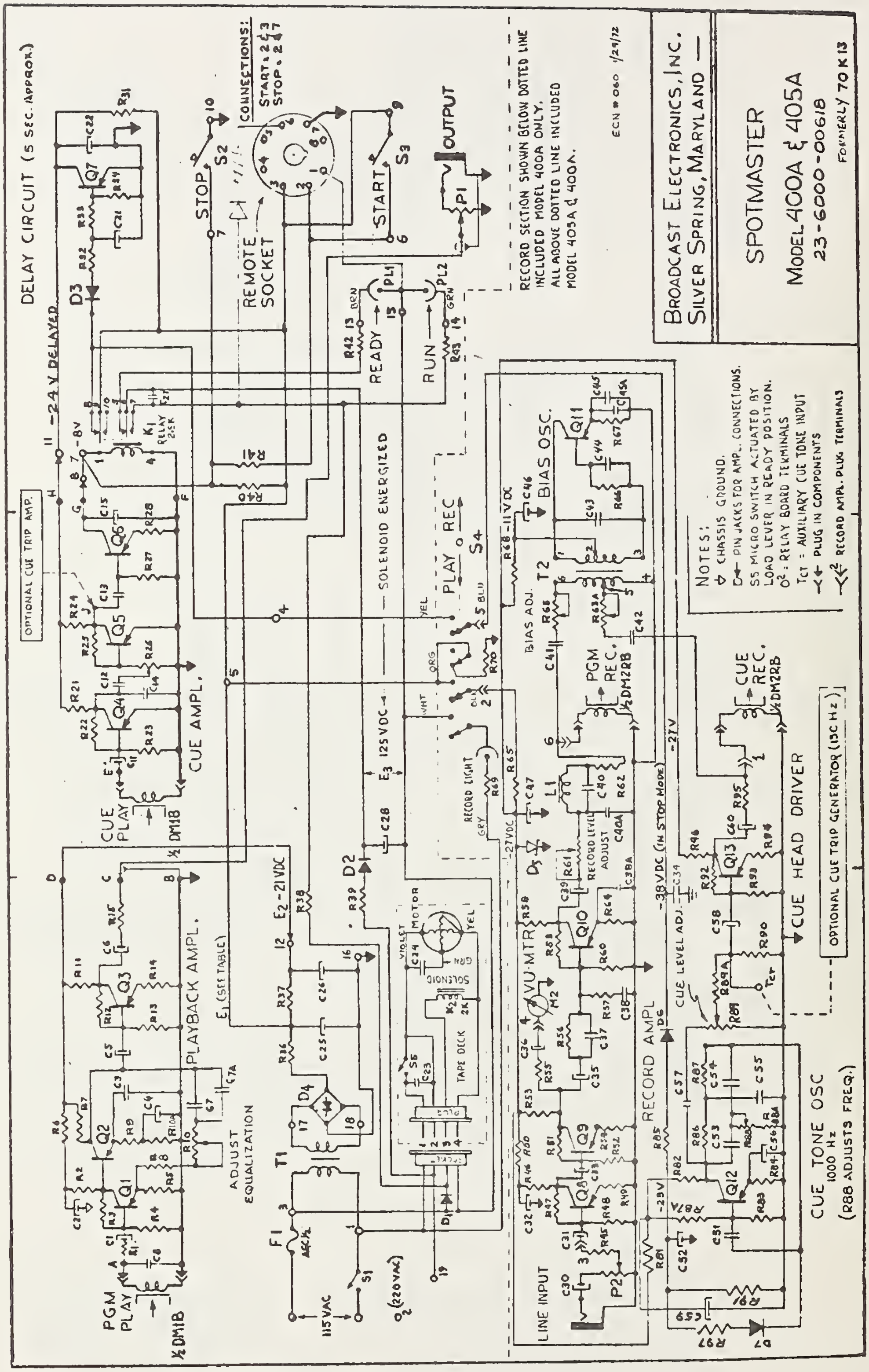
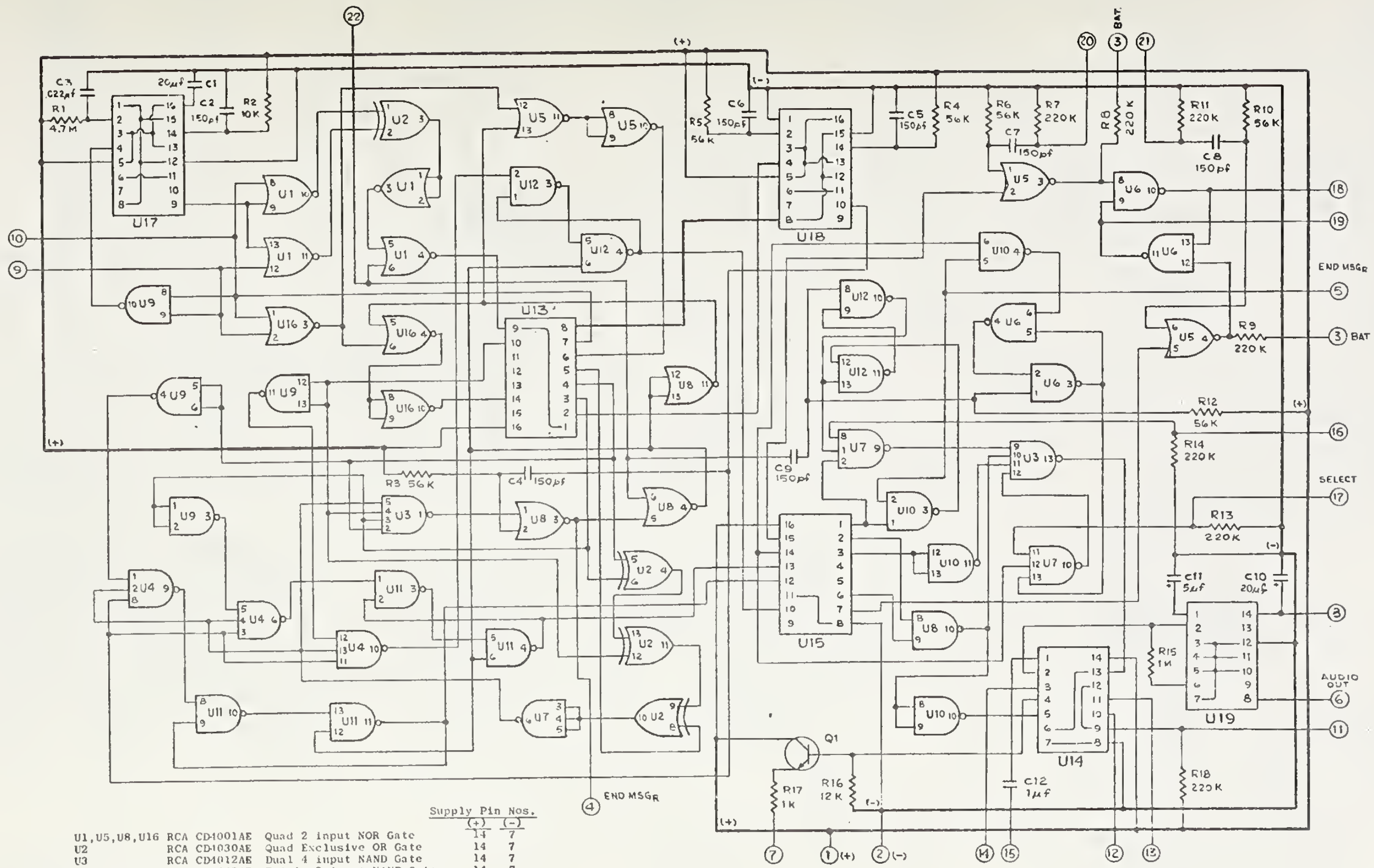
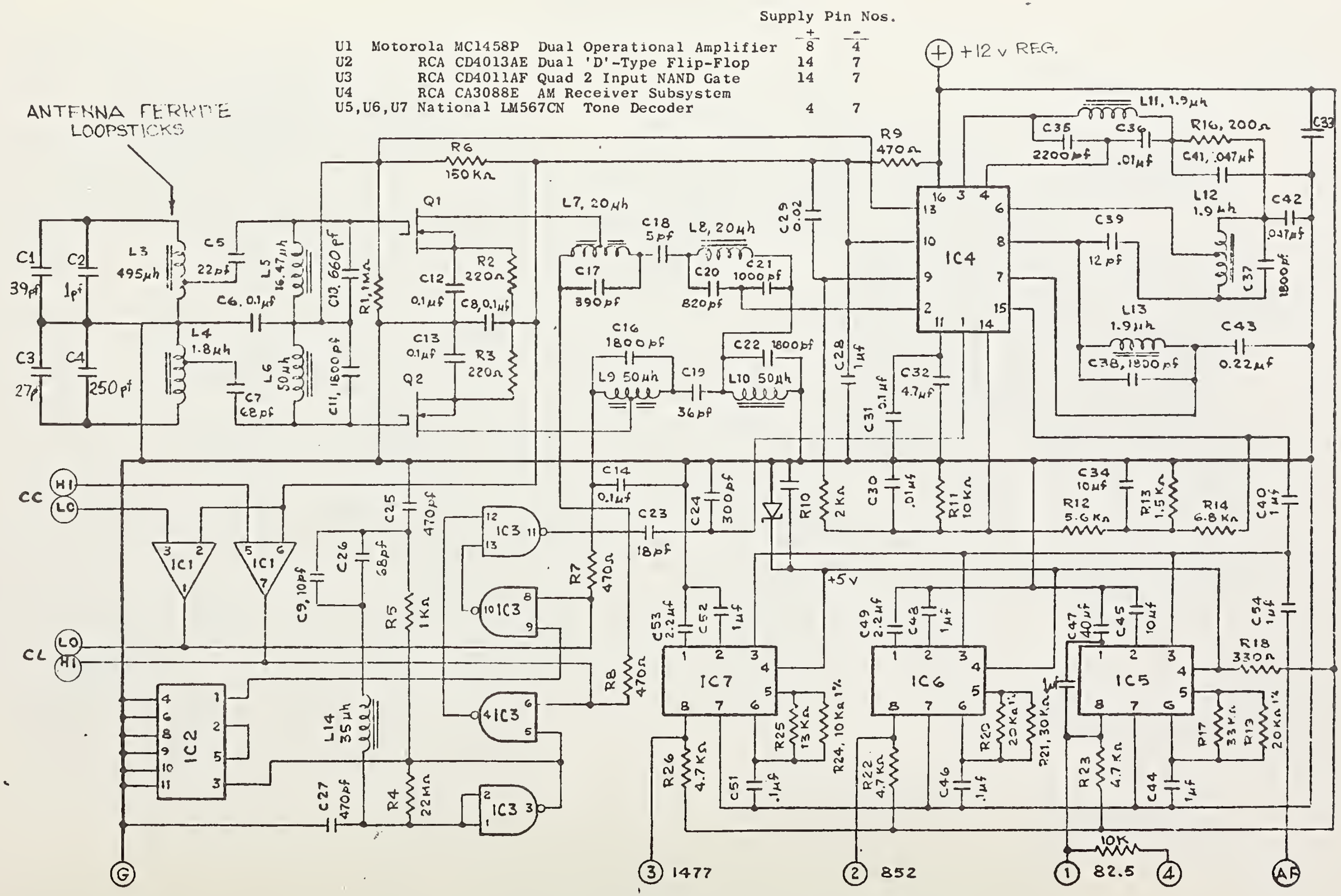


Figure 64. Tape Recorder.



			Supply Pin Nos. (+)	Supply Pin Nos. (-)
U1,U5,U8,U16	RCA CD4001AE	Quad 2 input NOR Gate	14	7
U2	RCA CD4030AE	Quad Exclusive OR Gate	14	7
U3	RCA CD4012AE	Dual 4 input NAND Gate	14	7
U4,U7	RCA CD4023AE	Triple 3 input NAND Gate	14	7
U6,U9,U10,U11,U12	RCA CD4011AE	Quad 2 input NAND Gate	14	7
U13	RCA CD4015AE	Dual 4-bit Shift Register	16	8
U14	RCA CD4016AE	Quad Bilateral Switch	14	7
U15	RCA CD4028AE	Decoder BCD to Octal	16	8
U17,U18	Motorola MC14528	Dual Retriggerable One-shot	16	8
U19	National LM380N	Audio Amplifier	14	7

Figure 65. Decoder Circuit Board.



			+	−
U1	Motorola MC1458P	Dual Operational Amplifier	8	4
U2	RCA CD4013AE	Dual 'D'-Type Flip-Flop	14	7
U3	RCA CD4011AF	Quad 2 Input NAND Gate	14	7
U4	RCA CA3088E	AM Receiver Subsystem		
U5,U6,U7	National LM567CN	Tone Decoder	4	7

Figure 66. Portable Receiver Circuit Board.

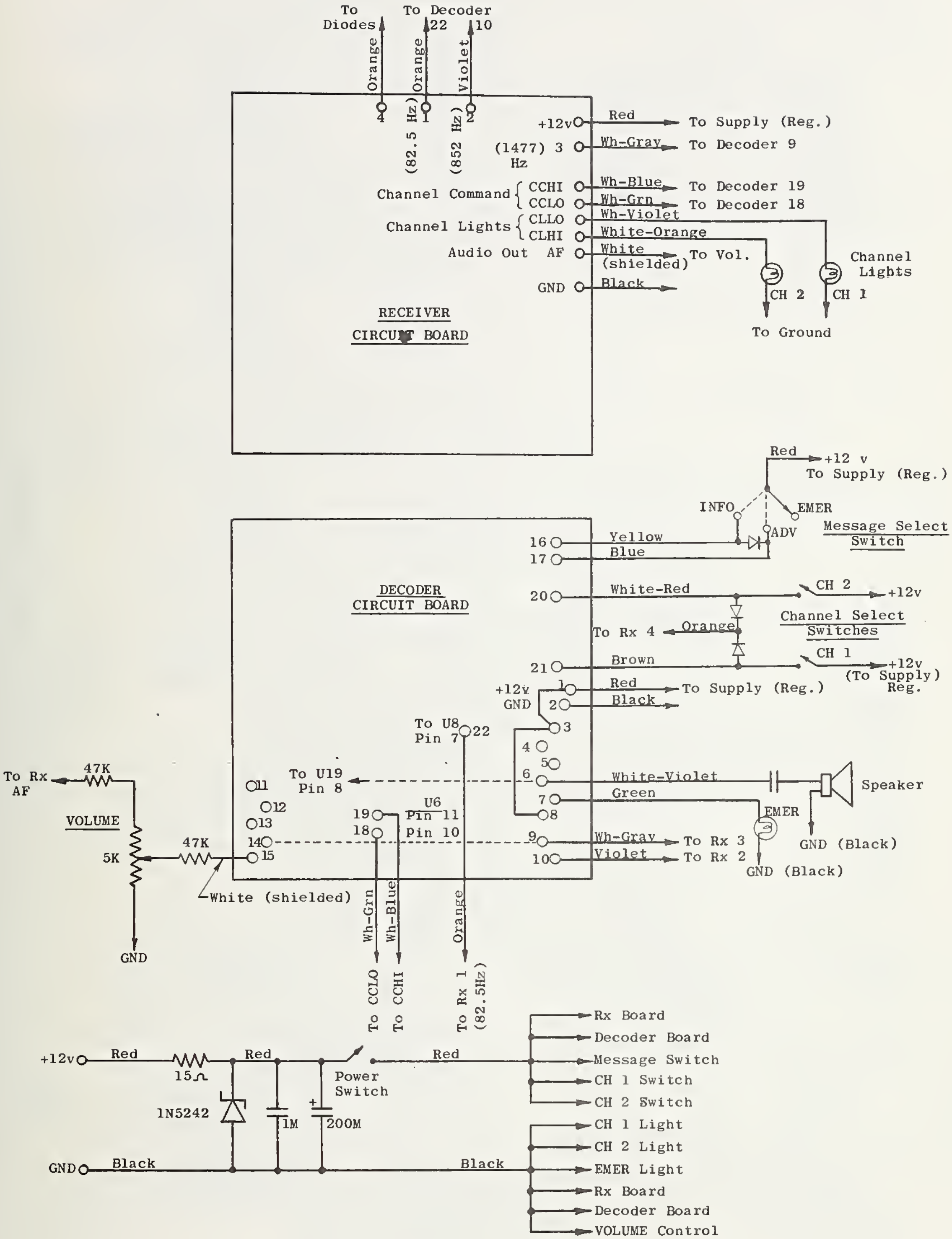


Figure 67. Portable Receiver Wiring.

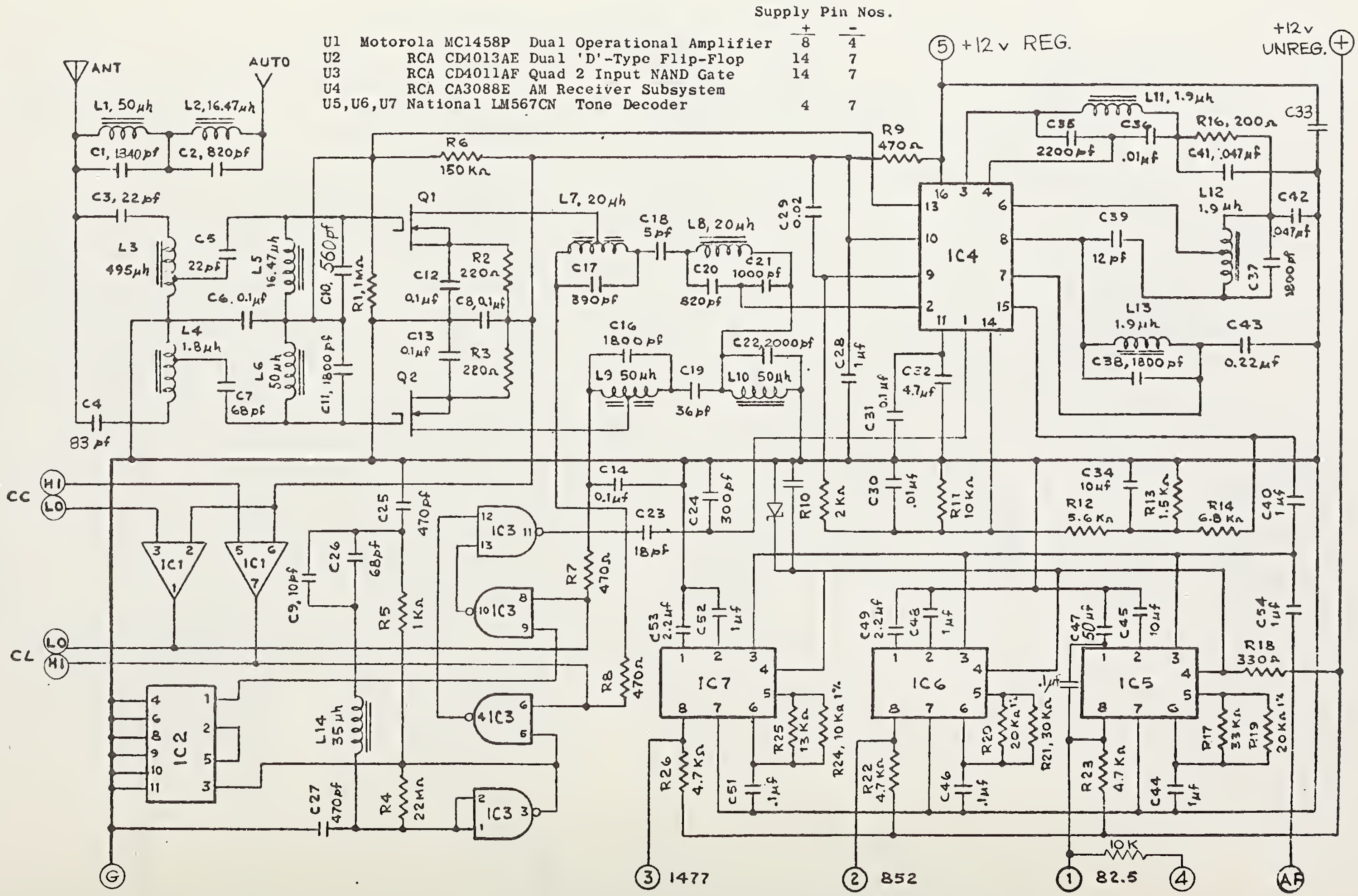


Figure 68. Adaptor Receiver Circuit Board.

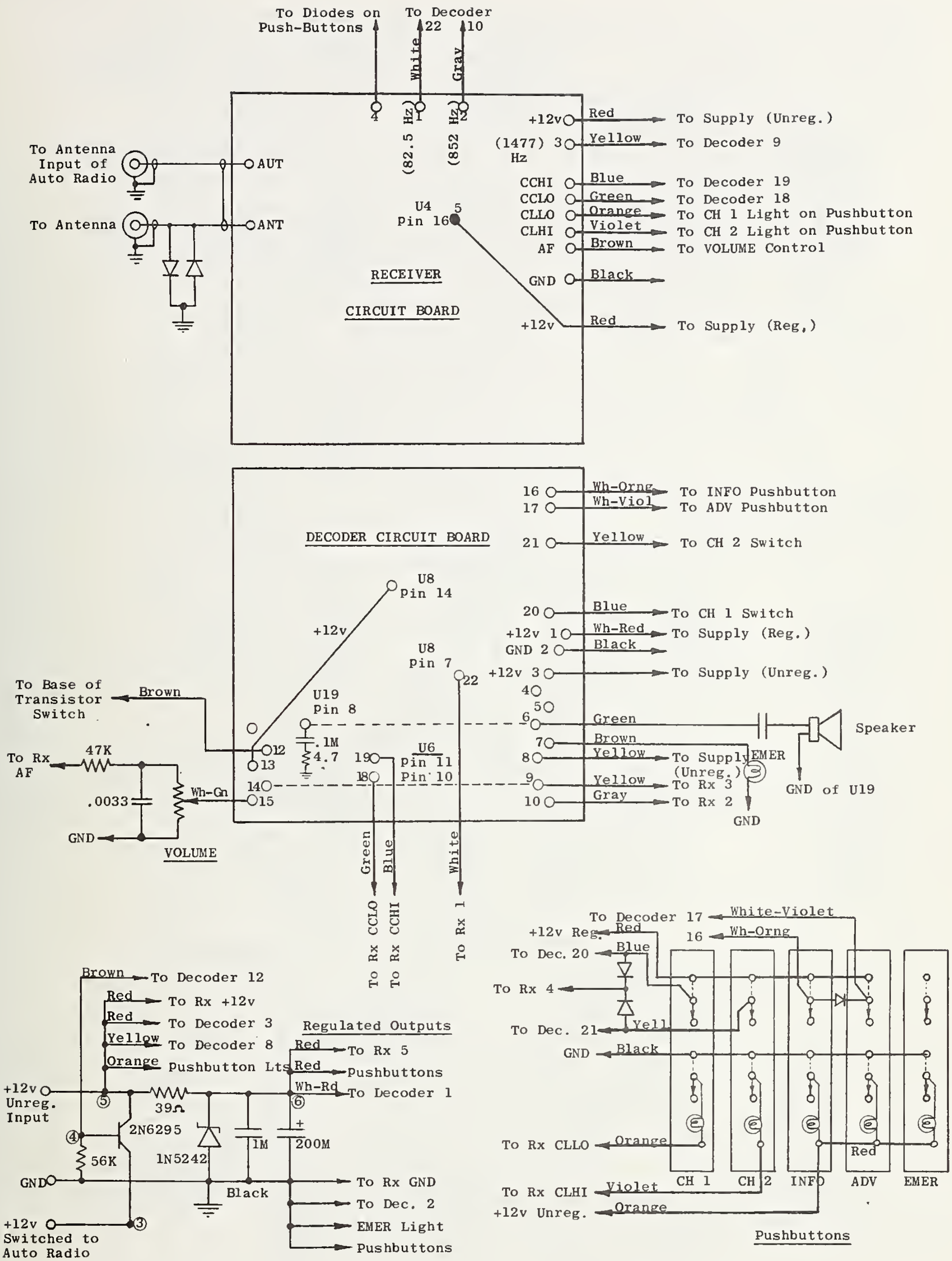


Figure 69. Adaptor Receiver Wiring.

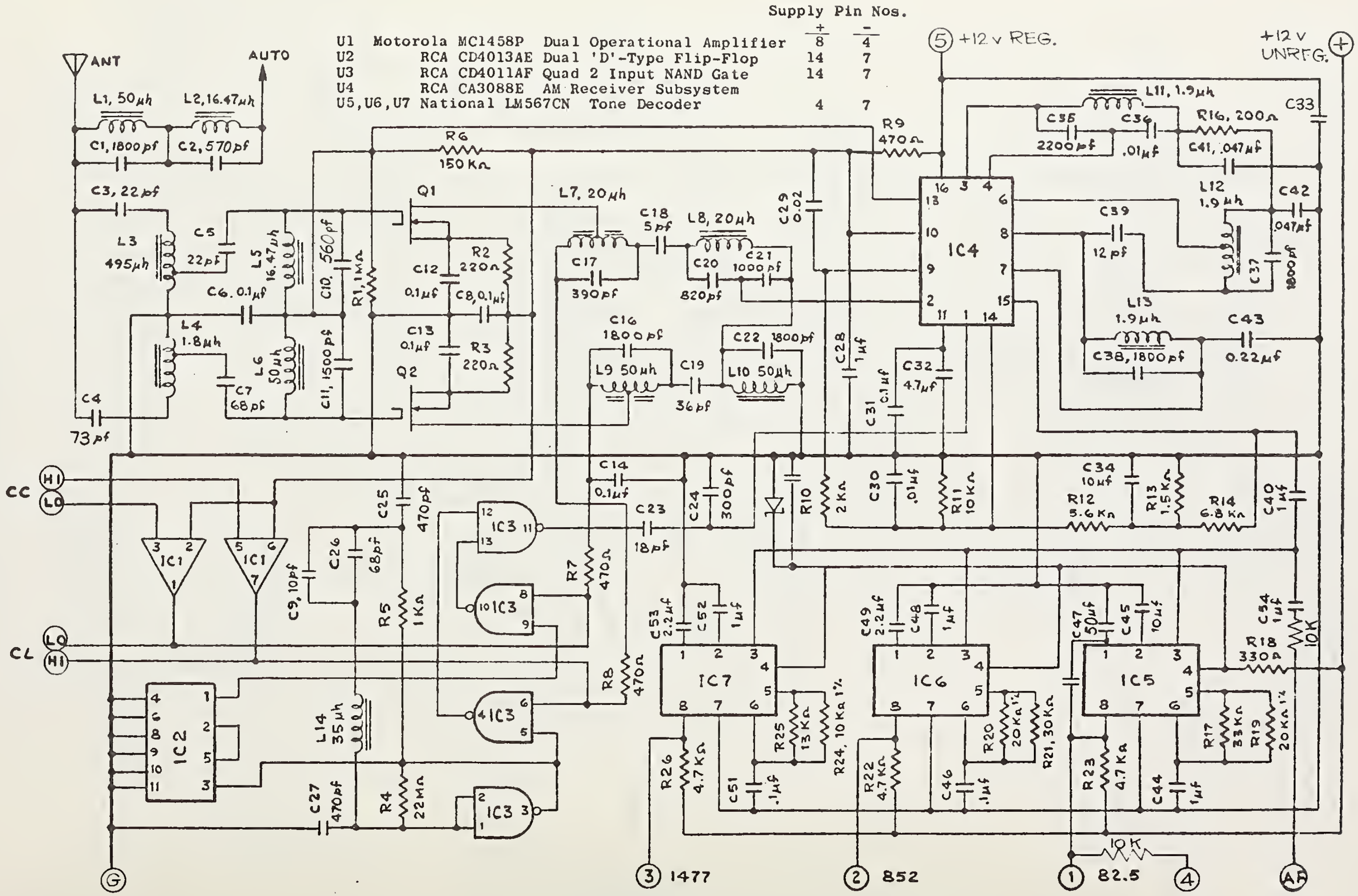


Figure 70. Integrated Receiver Circuit Board.

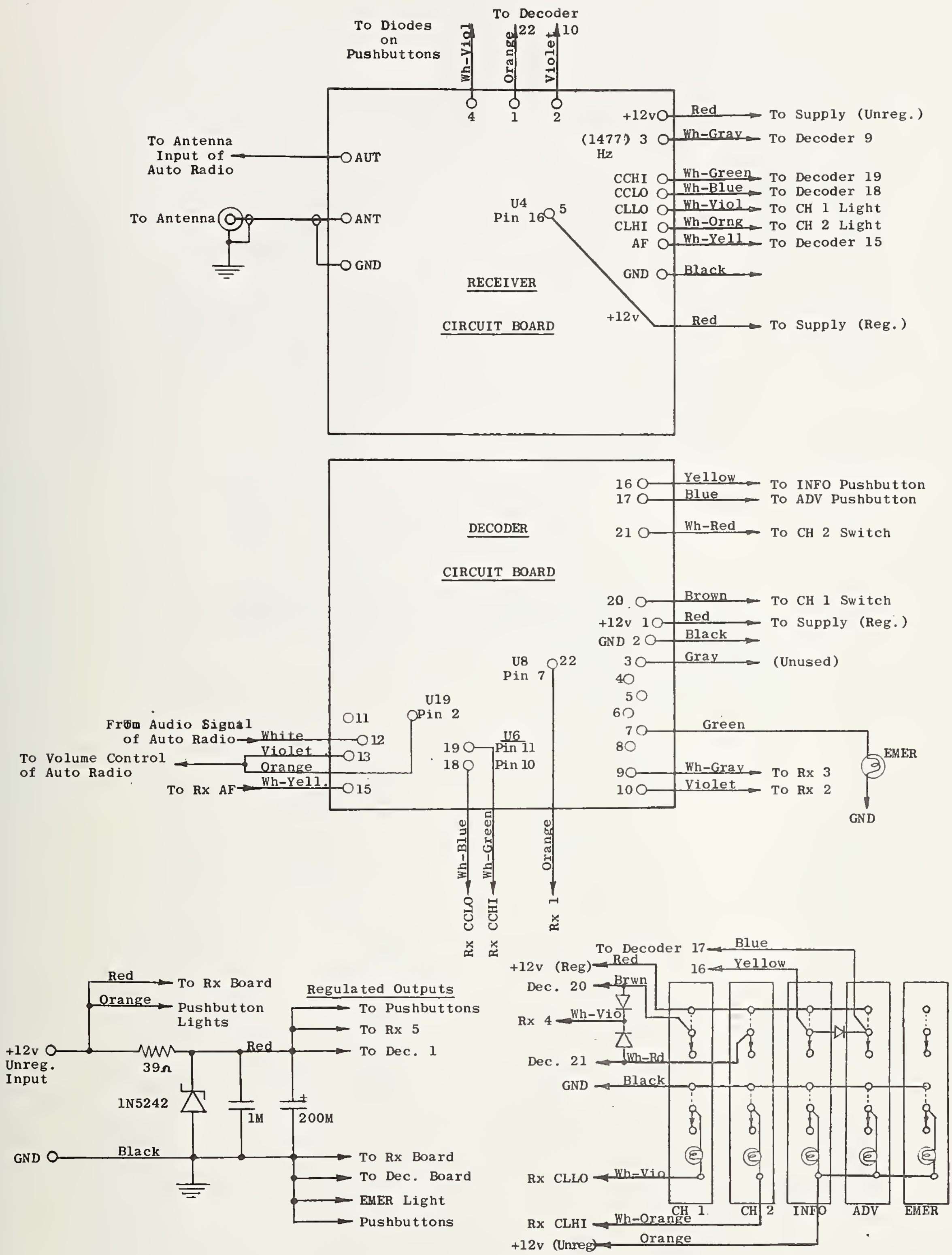


Figure 71. Integrated Receiver Wiring.

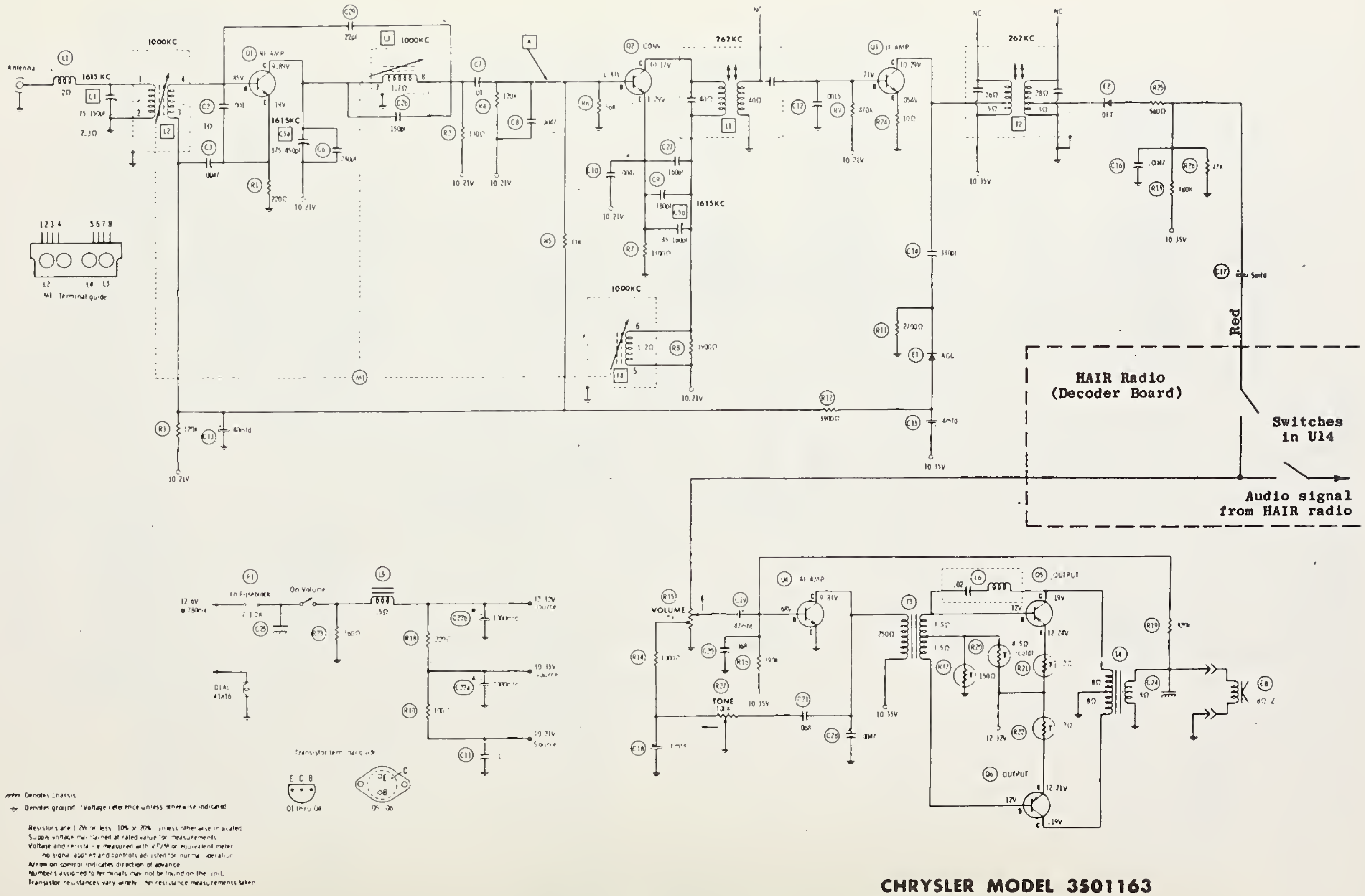


Figure 72. Auto Radio of Integrated Receiver.

APPENDIX E

EQUIPMENT INSTALLATION AND OPERATION

1.0 EQUIPMENT CONTROLS

1.1 Encoder

a. Power - power switch on and off.

b. Message buttons - sets tone code for message and enables recorder

EMER - 1010, 1010, 1010, 1111 (emergency warning) Priority 1

FIXED EMER - 0000 Voice	Priority 1
TRIP ADV - 1001 Voice	Priority 2
TRIP INFO - 0011 Voice	Priority 3

CH 1 - 1100	Automatically switches receiver on channel 2 to channel 1
CH 2 - 0110	Automatically switches receiver on channel 1 to channel 2
END MSG - 1111	Must be entered to terminate each of the above 6 message commands.

c. ENTER - activates command set by message button.

d. Gain control - adjusts amount of audio compression when using microphone.

e. SAT switch - controls presence of 82.5 Hz sub-audible tone

EXT - Connects SAT to output BNC terminal on rear panel, and disconnects SAT from cable output.

OFF - Disconnects SAT to all outputs.

INT - Connects SAT to cable output and disconnects SAT to BNC terminal on rear panel.

f. Output Adj. (Rear panel) - Controls amplitude level of composite signal (tone codes and voice) in output cable. This control does not adjust the amplitude of the SAT.

g. SAT amplitude (screwdriver adjust on rear panel) - adjusts amplitude level of SAT.

1.2 Recorder

a. OFF-GAIN - power on and off, adjusts amplitude level of input signal during recording. Does not control output signal.

b. RECORD-PLAY - Switches operation to either record input signal or playback tape to output jack. Note: Playback signal exists during recording.

c. STOP-START buttons - activates tape motion for record or playback.

Note: When plugged into encoder control cable, tape motion is activated automatically by encoder during input of tone codes which then enables the tape to be activated by the microphone switch during voice intervals of messages, playback or record.

d. LEVEL - (Screw adjust on rear panel.) Adjusts amplitude of output signal (tape playback).

1.3 Transmitter

a. POWER - power on and off.

b. RF OUTPUT - adjusts rf carrier amplitude, calibrated scale based on unmodulated carrier, 50 Ω (matched) load at output terminal on rear panel.

c. MODULATION - adjusts amplitude of modulating signal. Note: Percent modulation also depends upon rf power and must be measured with an oscilloscope connected to output monitor terminal on front panel.

d. Modulation inputs.

TONE - Input for SAT from encoder, rear panel BNC jack, activated with SAT switch in EXT. position.

RCDR - Input for voice from tape playback, or may be used for signals directly from encoder.

e. Output power - transmitter RF output which should be reasonably well matched to 50 ohms (vswr $<$ 5).

2.0 INSTALLATION OF ROADSIDE TRANSMITTER SYSTEM

2.1 Weatherproof Transmitter Enclosure

Locate in center of zone at least 30 feet from center antenna.

2.2 Whip Antennas

a. Locate antenna near center of desired coverage zone. If possible, locate antenna 30 to 100 feet from highway.

b. If three antennas are used, locate two additional sites at distances from the center antenna corresponding to frequency. 530 kHz = 1480 feet. 1606 kHz = 620 feet.

c. Support each whip antenna with rigid base bracket. It is not necessary to ground this support.

d. If site is over earth, drive at least one ground rod into earth, at least 3 feet long, (preferably 6 to 8 feet). Otherwise, connect to available grounding system.

e. Install appropriate matching network box near each antenna base. Box may be clamped to antenna below feed point.

f. Connect ground wire to ground terminal of each matching network box. Connect matching network output to antenna feed point.

g. Lay out RG-58 coaxial feed lines to antennas. Follow Figure 15 for cable details with 3 antenna array. If single antenna is used, the cable may be of any length; however, cable losses should be considered. Note: At 530 kHz, the cable to a single antenna may need to be a minimum of 100 or 200 feet to prevent distortion to the transmitter output waveform due to impedance mismatch.

h. Connect RG-58 cables to external connectors on rear panel of enclosure. Cable order is not important.

i. Connect proper capacitor depending on frequency inside power splitter. (For 3 antennas only.)

j. With power splitter box attached to inside rear panel of enclosure, connect RG-58 jumper cables between three output connectors and feed through connectors to antenna cables. (For 3-antennas only.)

k. Antenna system of one or three whip antennas is ready for tuning of matching networks.

l. At equipment enclosure, connect cable of antenna being tested directly to HAIR transmitter output.

m. Set up field strength meter greater than 50 feet from transmitter. Meter may be set on the ground near the antenna base to permit tuning procedure by one person. With transmitter set to a low, convenient output level, tune field strength meter to receive radiated signal.

n. Remove cover at matching network box and adjust tuning slug for maximum field strength. Peak reading should be obtained with no personnel located closer than 10 feet from antenna. Replace box cover.

o. Repeat l, m, n above for each antenna.
Note: It is advisable to observe transmitter waveform with an oscilloscope to be certain that no distortion exists in sine wave of carrier signal. If distortion exists, first determine that transmitter output is reasonably well matched (vswr < 5). Adjust trim capacitors in transmitter driver and output amplifier circuits. At 530 kHz, if antenna is closer than 50 feet from transmitter, distortion may be eliminated by increasing the length of the RG-58 antenna cable to 200 feet or more. A quick check of transmitter performance can be made with output connected to 50 ohm dummy load.

p. If desired, the radiation efficiency of each antenna may be measured after the tuning is completed. Set transmitter power into antenna base to 1 watt (20 volts peak-to-peak) and measure field strength at 200 feet from antenna. This measurement should not be made in a direction away from the transmitter or the antenna cable. The following values are expected, corresponding to the efficiencies shown.

530 kHz	6.5 mv/m	0.35%
1606 kHz	23 mv/m	4.6%

If the measured values are significantly less than the above,

check the transmitter power level, the tuning of the matching inductance, and all connections. If necessary, measure impedances of antenna, matching network, and of both when tuned for series resonance to determine resistance of antenna circuit.
When more than 1 watt is transmitted the matching coil becomes warm or hot and can become detuned. Thus, networks should be retuned after reaching stable temperature. Note: Do not attempt to transmit more than 5 watts into one antenna at 530 kHz using ferrite pot-core matching inductances supplied.

2.3 Cable Antenna

a. Locate site for cable placement, either above ground or below ground. Cable should be located as near the highway lanes as possible where radio coverage is needed.

b. Make appropriate connections to transmitter. If cable is unbalanced, reasonably well matched, and if single cable is to be fed, the connection may be made directly to transmitter coaxial RG-58 cable. If two cables are to be fed, they may be connected in series or in parallel depending upon the impedances. Otherwise, employ suitable baluns, power dividers, impedance transformers, etc., to provide proper unbalanced 50 ohm match with transmitter.

2.4 Adjustment of Encoder and Recorder

Several arrangements of connecting the encoder and recorder to the transmitter are possible for transmitting the coded HAIR messages. In each case there are three important adjustments which must be made: ratio of SAT to audio FSK tones, percent amplitude modulation of carrier, and power level of transmitted carrier. An oscilloscope (with X10 probe) must be used to set these values.

The SAT can be supplied from the encoder either internally with the coded tones and voice through the phone plug, or externally through the BNC jack on the rear panel. In any case, the amplitude of the SAT is

adjustable only with a screwdriver through a hole in the rear panel of the encoder. It should be noted that the tape recorder on playback reduces the SAT 50% relative to the other message frequencies.

2.4.1 Live Transmission, Encoder Only

a. Connect encoder to transmitter as follows:

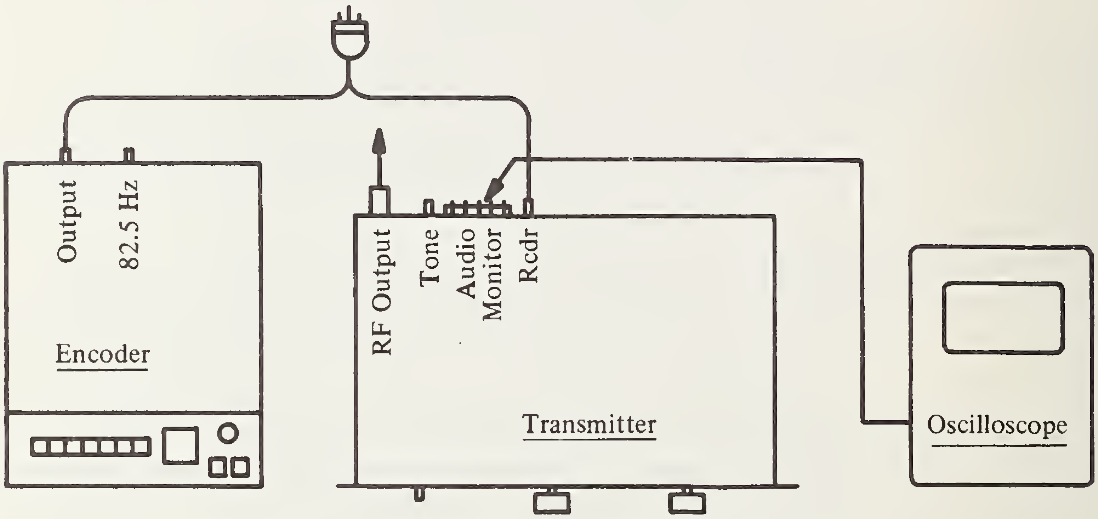


Figure 73. Line Transmission Hookup.

b. With transmitter turned off or with MODULATION control set to minimum, connect signal output line of encoder to RCDR jack on rear of transmitter. Also connect monitor oscilloscope to this line.

c. Turn encoder on by depressing POWER button.

d. Set 82.5 Hz switch to OFF.

e. Generate emergency warning signal:
Depress EMER button.
Depress ENTER button.

f. Adjust amplitude of audio tones with OUTPUT ADJ knob on rear panel of encoder using oscilloscope. Set peak-to-peak amplitude to 4 divisions (uncalibrated).

g. Stop emergency warning signal:
Depress END MESS button.
Depress ENTER button.

h. Turn 82.5 Hz switch to INT.

i. Observe SAT waveform on oscilloscope. Adjust peak-to-peak amplitude to 3 divisions to give a SAT/FSK ratio of 75%.
Note: Distortion of SAT sinusoidal waveform occurs with excessive SAT amplitude and must be avoided. If the desired SAT amplitude cannot be achieved without distortion, reduce amplitude of audio tones and repeat procedure.

j. Encoder is now set for operation. Adjust percent modulation in transmitter next.

2.4.2 <u>Recorded Message, Internal SAT</u>

a. Connect encoder, tape recorder and transmitter as follows:

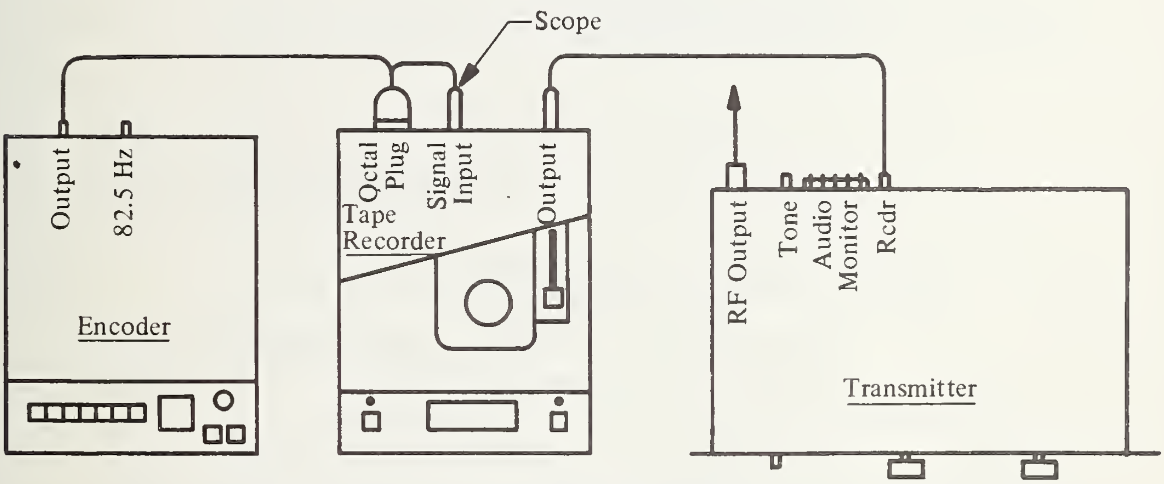


Figure 74. Internal SAT Hookup.

Connect octal and phone plubs on common line from encoder to recorder. Connect recorder output to RCDR jack of transmitter.

b. Set SAT/FSK ratio to 150% on signal line into recorder as seen by oscilloscope. This may be done as follows.

c. Turn on encoder by depressing POWER button.

d. Turn 82.5 Hz switch to INT.

e. Observe waveform on oscilloscope and, if undistorted, set peak-to-peak amplitude to 3 divisions (uncalibrated).

f. Switch 82.5 Hz to OFF.

g. Generate warning signal:
Depress EMER button.
Depress ENTER button.

h. Set peak-to-peak amplitude of audio tones to 2 divisions with OUTPUT ADJ knob on rear panel of encoder.
Note: If amplitude cannot be decreased to this level, increase SAT and repeat procedure.

i. Turn off warning signal:
Depress END MESS button.
Depress ENTER button.

j. Turn on 82.5 Hz switch to INT.

k. Encoder is now ready for recording composite message signals.

2.4.3 <u>Recorded Message, External SAT</u>

a. Connect encoder, recorder, and transmitter as follows:

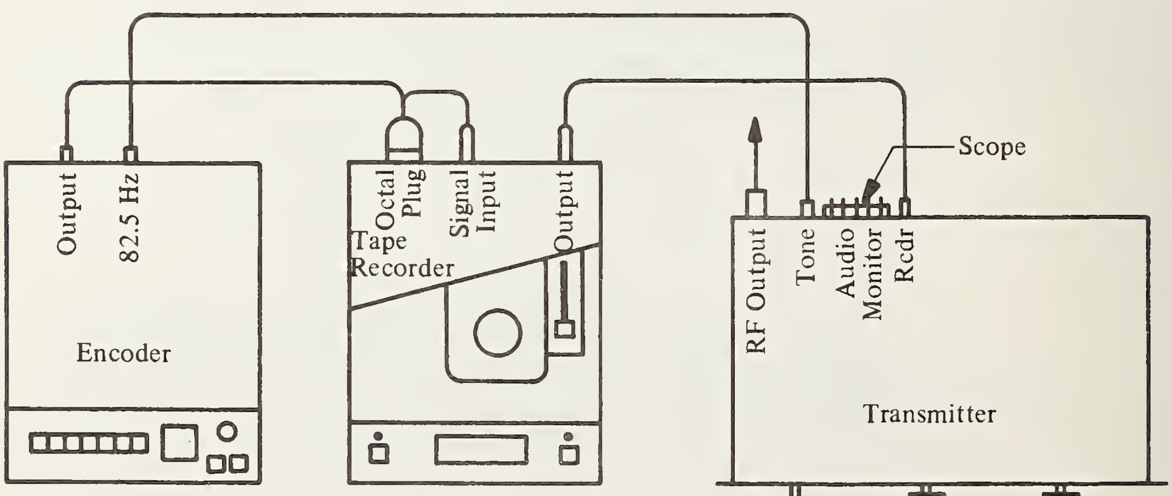


Figure 75. External SAT Hookup.

These connections are the same as in 1.4.2 with an additional cable from the EXT. SAT output on the encoder to TONE input of transmitter. Also, connect the oscilloscope to the modulation monitor on terminal strip on rear panel of transmitter.

b. Insert a cartridge with a fully erased tape into the recorder. Use a short loop (20 second cartridge).

c. Turn on encoder by depressing POWER button.

d. Turn on recorder and set to RECORD.

e. Generate emergency warning signal with encoder.
Depress EMER button.
Depress ENTER button.

f. Set 82.5 Hz switch to OFF.

g. Adjust GAIN of recorder to give peak levels at about -3 to -5 dB on VU meter.

h. Start tape by depressing START button on recorder. Record one cycle of the tape loop with audio tones of warning signal (without SAT).

i. Stop tape by depressing STOP button.

j. Turn mode switch on recorder to PLAY.

k. With small screwdriver, turn amplitude of SAT on rear of encoder to minimum.

l. Switch 82.5 Hz to EXT.

m. Start tape playback by depressing START button recorder.

n. Observe audio tones on oscilloscope and adjust amplitude with LEVEL control on rear of recorder. Set peak-to-peak amplitude to 4 divisions (uncalibrated).

o. Stop tape by depressing STOP button on recorder.

p. With small screwdriver increase amplitude of SAT until peak-to-peak amplitude is 3 divisions to achieve 75% SAT/FSK ratio.

Note: If SAT waveform distorts due to excessive amplitude, decrease amplitude of audio tones with LEVEL control and repeat steps above beginning with k.

q. Encoder and tape recorder are now set for recording and playback. The next step is to set percent modulation of transmitter.
Note: The adjustable controls of the encoder and tape recorder should not be changed without recalibration. The encoder compression GAIN control can be adjusted at any time.

2.5 Adjustment of Transmitter

Two adjustments are required in the transmitter: power level of carrier and percent modulation.

a. Turn transmitter OUTPUT and MODULATION controls to minimum. Transmitter is assumed to be connected to properly matched load. See 1.2, paragraph o.

b. Connect oscilloscope to OUTPUT MONITOR terminal on front panel, or remove top cover and connect oscilloscope directly to output line.

e. Turn transmitter on.

d. Turn OUTPUT control until desired power level of unmodulated carrier is achieved. This power level is given by

$$P = \frac{(E)^2}{(20)} \text{ watts}$$

where E is the peak-to-peak amplitude of the carrier in volts. (This formula assumes a perfectly matched antenna, and is accurate to 10% for vswr < 2.)

e. Adjust vertical gain of oscilloscope to display carrier over 4 divisions peak-to-peak. This permits percent modulation to be read directly as follows. Each 1/5 division marker (seen on Tektronic oscilloscope gradicules) above the peak carrier level corresponds to 10% modulation.'

f. Turn on encoder or recorder to supply the emergency warning signal with SAT for the modulating signal.

g. Increase MODULATION control until the peak modulation is at the desired level as seen on the oscilloscope. For example, 50% modulation occurs when the peak of the modulating signal rises one major division above the upper unmodulated carrier level, or six total divisions peak-to-peak of modulated carrier.

3.0 INSTALLATION OF AUTOMATIC RECEIVERS

3.1 Portable Receiver

Installation consists simply of inserting plug into cigarette lighter receptacle of vehicle. If such receptacle does not exist in vehicle, make appropriate connections to 12v DC supply with the red wire to positive.

3.2 Integrated Receiver

a. Mount unit in desired location.

b. Make sure the receiver case is connected to the electrical ground of vehicle.

c. Connect red wire from unit to +12v DC.

d. Plug antenna lead into connector on right side of receiver.

3.3 Adaptor Receiver

a. Mount unit in desired location.

b. Connect the black ground wire to the electrical ground of the vehicle.

c. Connect the red wire to +12v DC.

d. Connect yellow wire (switched +12v DC) to the auto radio +12v power input wire.

e. Plug antenna lead into ANT inside of Adaptor unit.

f. Plug jumper antenna cable from AUX inside of Adaptor to antenna input of auto radio.

4.0 OPERATION OF ENCODER/TAPE RECORDER

This section presents step-by-step instructions for operating the encoder and for recording and playing back the messages for radio transmission. It is assumed that the transmitting system has been properly adjusted in accordance with Sections 2.4 and 2.5. When recording, be sure the tape recorder is set to RECORD mode with tape stopped.

4.1 Operation of Encoder

a. Depress POWER switch.

b. Depress button of desired message.

c. Depress ENTER button and wait at least two seconds for tones to enter before continuing.

d. If EMER was selected, the emergency signal will be generated continuously until the END OF MESSAGE button is depressed.

e. For a voice message, hold microphone close to mouth and depress microphone button while speaking. The compression GAIN control may be set to indicate 15-20 dB compression as indicated by the meter at peak levels while speaking normally.

f. To terminate the message, depress END MSG button.

g. Depress ENTER button.

Note: When recording, the tape drive should become active automatically when a message code is entered and when the microphone button is depressed.

4.2 Operation of Tape Recorder

a. Insert an appropriate tape cartridge using the PLAY-RELEASE lever. Be sure lever is fully forward for recording or playback modes. If a recorded message is to be made a

fully erased tape must be used as the recorder contains no erasing capability. Tape erasure must be accomplished externally with a bulk erasure on an entire cartridge.

b. Turn recorder on with GAIN knob.

c. Set mode switch to RECORD or PLAY.

d. For recording, adjust GAIN control to provide a meter reading not exceeding 0 VU using a sample of the recording signal. For voice, the meter should not peak above 0 VU.

e. Activate tape drive with START and STOP buttons. For recording from the encoder, however, the tape drive is activated remotely by the encoder.

f. Adjust output (playback) level with LEVEL adjust control on rear panel. Playback signal exists during recording.

4.3 <u>Operation of Automatic Receivers</u>

a. Turn on Portable and Integrated radios with VOLUME knob. The Adaptor radio turns on immediately when supplied with +12 v DC power.

b. Depress desired CH1 or CH2 button.

c. Depress desired message priority button. (With the Portable receiver, switch to desired message priority.)

If EMER priority is selected, receiver should respond only to EMER and FIXED EMER messages.

If ADV priority is selected, receiver should respond only to ADV, EMER and FIXED EMER messages.

If INFO priority is selected, receiver should respond to all message priorities.

d. When receiving INFO or ADV messages repetitively with continuous subaudible tone, the receiver should automatically release after reception of the first message. To reactivate the automatic receiver depress the channel select button (to break the SAT).

APPENDIX F

EXPERIMENTAL RADIO STATION

CONSTRUCTION PERMIT AND LICENSE

FCC Form 450-B
September 1972

UNITED STATES OF AMERICA

FEDERAL COMMUNICATIONS COMMISSION

EXPERIMENTAL

RADIO STATION CONSTRUCTION PERMIT

AND

LICENSE

EXPERIMENTAL (RESEARCH)
(Nature of service)

CONTRACT DEVELOPMENTAL XC MO
(Class of station)

K C 2 X C M
(Call sign)

6305-ER-PL-73
(File number)

NAME ATLANTIC RESEARCH CORPORATION

Mobile: Fairfax County, Virginia
(Location of station)

(Location of authorized remote control point)

Subject to the provisions of the Communications Act of 1934, subsequent acts, and treaties, and all regulations heretofore or hereafter made by this Commission, and further subject to the conditions and requirements set forth in this license, the licensee hereof is hereby authorized to use and operate the radio transmitting facilities hereinafter described for radio communication.

Frequency	Emission Designator	Authorized Power (Watts)	Special Provisions
530 kHz	2.2A2, 6A3	15 (input)	
1606 kHz	2.2A2, 6A3	15 (input)	

Equipment: (3) Low Power Broadcast Inc. 25C and 4C.

Frequency Tolerance: 0.01%

Hours of Operation: Unlimited

Operation: In accordance with Section 5.202(c) of the Commission's Rules.

Special Conditions: SEE ATTACHED SHEET

The above frequencies are assigned on a temporary basis only and are subject to change at any time without hearing.

This authorization is granted subject to the condition that no harmful interference is caused to any other station or service and may be cancelled at any time without hearing if, in the judgment of the Commission, such action should be necessary.

This license is issued on the licensee's representation that the statements contained in licensee's application are true and that the undertakings therein contained, so far as they are consistent herewith, will be carried out in good faith. The licensee shall, during the term of this license, render such service as will serve public interest, convenience, or necessity to the full extent of the privileges herein conferred.

This license shall not vest in the licensee any right to operate the station nor any right in the use of the frequencies designated in the license beyond the term hereof, nor in any other manner than authorized herein. Neither the license nor the right granted hereunder shall be assigned or otherwise transferred in violation of the Communications Act of 1934. This license is subject to the right of use or control by the Government of the United States conferred by Section 606 of the Communications Act of 1934.

FEDERAL COMMUNICATIONS COMMISSION · U.S.

This authorization effective November 15, 1973 and will expire 3:00 A.M. EST December 1, 1974 - or on the expiration of the contract designated on the attached sheet, whichever is earlier.

FEDERAL COMMUNICATIONS COMMISSION.

Ben F. Waple

Secretary.

F.C.C. · WASHINGTON, D. C.

1. Upon completion of the station, in accordance with the terms of this permit, the grantee shall, on the forms and in the manner prescribed from time to time by the Commission, make it appear to the satisfaction of the Commission that all the terms, conditions, and obligations set forth in the application and in this permit have been fully met, and shall apply for a radio station license; upon such showing and application, and upon a finding by the Commission that since the granting of this permit no cause or circumstance has arisen which, in the judgment of the Commission makes the operation of the station against the public interest, a radio station license will be issued by the Commission for the operation of the station. The license will contain the conditions specified in Section 309 of the Communications Act of 1934, and such other terms and conditions as the Commission may prescribe.

2. This permit shall not vest in the grantee any right to operate the station, nor any right to a license authorizing the use of the particular frequency or the amount of power, or the time of operation herein specified. The Commission, in issuing this permit, reserves the right to assign whatever frequency, power, or time of operation it deems best calculated to serve public interest, convenience, or necessity. The terms of said license as to frequencies, power, emission, time of operation, and scope of communication are expressly made subject to the exercise of said reserved right.

3. Nothing contained herein shall be construed as a finding by the Commission on the question of marking or lighting of the antenna system should future conditions require. The permittee expressly agrees to install such marking or lighting as the Commission may hereafter require under the provisions of Section 303 (q) of the Communications Act of 1934.

4. This permit shall become automatically forfeited if the said station is not ready for operation within the time above specified, unless prior to the expiration of said permit the Commission shall have granted an extension of time. Upon proper showing, made to it by the grantee, prior to the expiration of such period, the Commission may grant an extension if it finds that the grantee was prevented from completing the construction of said station by causes not under grantee's control.

5. Neither this permit nor the right granted herein shall be assigned or otherwise transferred to any person, firm, company, or corporation without the written consent of the Commission.

F.C.C. - WASHINGTON, D. C.

ATLANTIC RESEARCH CORPORATION

K C 2 X C M

6305-ER-PL-73

Special Conditions:

(1) This authorization is issued for the express purpose of conducting experimental operations described in the related application and required by Department of Transportation Contract No. DOT-FH-11-8045. The use of this radio station in any other manner or for any other purpose will constitute a violation of the privileges herein authorized.

(2) Except as subsequently authorized by the Commission, this radio station shall not be operated after the expiration date of the contract designated in the related application and enumerated above.

(3) Power changed to 15 watts input (unmodulated), emission to 6A3 and 1606 kHz authorized in lieu of 1610 kHz in accordance with final report of Ad Hoc 129.

GPO 887-051

FHWA

R&D